A NEW LOWER CAMBRIAN SHELLY FOSSIL BIOSTRATIGRAPHY FOR SOUTH AUSTRALIA

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ABSTRACT

Definition of early Cambrian chronostratigraphic boundaries is problematic with many subdivisions still awaiting ratification. Integrated multi-proxy data from well-resolved regional-scale schemes are ultimately the key to resolving broader issues of global correlation within the Cambrian. In Australia, early Cambrian biostratigraphy has been based predominantly on trilobites. Phosphatic shelly fauna have great potential as biostratigraphic

tools, especially in pre-trilobitic strata because they are widespread and readily preserved, but they have remained underutilised. Here we demonstrate their value in a new biostratigraphic scheme for the early Cambrian of South Australia using a diverse shelly fauna including tommotiids, brachiopods, molluscs and bradoriids.

Biostratigraphic data are derived from ten measured stratigraphic sections across the Arrowie Basin, targeting Hawker Group carbonates including the Wilkawillina, Wirrapowie and Ajax limestones and the Mernmerna Formation. The stratigraphic ranges of shelly fossils are predictable and repeatable across the Arrowie Basin, allowing three discrete shelly biozones to be identified, spanning Terreneuvian, Stage 2 to Series 2, Stages 3–4. The *Kulparina rostrata* Zone (new) and much of the overlying *Micrina etheridgei* Zone (new) are pre-trilobitic (predominantly Terreneuvian). The Cambrian Series 2, Stage 3 *Dailyatia odyssei* Zone (new) features a very diverse shelly fauna and will be described in detail in a separate publication. These zones provide robust means to correlate early Cambrian successions in neighbouring coeval basins in Australia, particularly the Stansbury Basin. Wider correlation is possible throughout East Gondwana, especially with South China.

Key words:

Small shelly fossils; tommotiids; Cambrian; biostratigraphy; correlation.

1. INTRODUCTION

The Arrowie Basin is a large (55,000 km^2) depositional basin situated in east-central South Australia (Fig. 1) that has one of the best exposed successions of lower Cambrian sedimentary packages anywhere in the world (Gravestock and Cowley, 1995; Zang et al., 2004; Jago et al., 2012). Calcareous and organophosphatic shelly fossils (often called "Small

Shelly Fossils" [SSF]) are ubiquitous across carbonate-dominated parts of the basin and have been described in a series of papers (Bengtson et al., 1990; Brock and Cooper, 1993; Brock and Paterson, 2004; Paterson and Brock 2007; Skovsted et al., 2006, 2008, 2009a, 2009b, 2009c, 2011a, 2011b, 2012, 2015a, 2015b, 2016; Topper et al., 2007; 2009; 2011a; 2011b; 2013a; Betts et al., 2014; 2015, in press; Larsson et al., 2014; Jacquet et al., 2014; Jacquet and Brock, 2015). This study integrates results derived from systematic sampling along 10 stratigraphic sections measured through the broadly coeval Wilkawillina, Wirrapowie and Ajax limestones that crop out as distinctive folded tracts in the Flinders Ranges (Fig. 1): In the north-west; the AJX-M and AJX-N (Figs. 2-3) sections. In the north-east; the MORO and MOG sections (Figs. 4-5). In the central Flinders Ranges; WAR, BALC, MMT, the Wilkawillina type section (WILK), and 10MS-W (Figs 6-10), and in the south; CR1 (Fig. 11). These stratigraphic sections intersect the lower part of the Hawker Group, from the Parachilna Formation to the Second Plain Creek Member (upper Wilkawillina Limestone) and Wirrapowie Limestones, and into the lower Mernmerna Formation (equivalent to depositional sequence sets C1.1A, C1.1B, C1.2 of Gravestock and Cowley, 1995) (Fig.12).

The biozones defined herein are derived from a total of 694 stratigraphic horizons sampled systematically at regular intervals (approximately 5–10 m) for shelly fossils. The data from these 10 stratigraphic sections have been used to define new shelly fossil biozones, reassess previously suggested schemes and discuss intrabasinal, regional and international correlation of the lower Cambrian package in the Arrowie Basin, South Australia.

Some authors have raised doubts about the utility of early Cambrian fossils for reliable biostratigraphic subdivision (Landing, 1994; Maloof et al., 2010; Landing and Geyer, 2012; Landing et al., 2013). The most often cited reasons for this include the strongly endemic nature of many early Cambrian fauna and the diachronous appearances of key taxa (Geyer, 2001; Peng et al., 2012). In response to this, chemostratigraphy has been suggested as

71 the method of choice for global correlation (Landing et al., 2013). However, there remains
72 some doubt regarding the application of chemostratigraphic data (Swart and Eberli 2005;
73 Swart 2008; Parkhaev, 2014).Biostratigraphic ranges of key early Cambrian shelly fossils
74 have been shown to be invaluable tools for relative dating and correlation (Devaere et al.,
75 2013; Guo et al., 2014; Rozanov, 1995; Steiner et al., 2004; Steiner et al., 2007; Yang et al.,
76 2014). Integration of regional biostratigraphic schemes, chemostratigraphic data are crucial to
77 solving broader issues of global correlation within the Cambrian system.

78

79 ## 2. PREVIOUS BIOSTRATIGRAPHIC WORK

80 Early contributions to provide stratigraphic context to the succession of Cambrian
81 strata in the Flinders Ranges were made by Robert Etheridge (Etheridge, 1890), Griffith
82 Taylor (Taylor, 1910), Walter Howchin (Howchin, 1922, 1925), Robert Bedford (Bedford
83 and Bedford, 1939 and references therein), Douglas Mawson (Mawson, 1937, 1938, 1939)
84 and R.W. Segnit (Segnit, 1939). Daily (1956) produced the first biostratigraphy of the lower
85 Cambrian succession of South Australia by establishing 12 informal "faunal assemblages"
86 that were (until relatively recently) widely used for broad regional correlation in South
87 Australia (see also Daily, 1972). Unfortunately, Daily's (1956) faunal assemblages were not
88 accompanied by formal taxonomic descriptions or definition of precise boundaries. In
89 addition, only general locality data and vague stratigraphic ranges of the most important
90 diagnostic taxa were provided, preventing accurate correlation across and between adjacent
91 basins (Jago et al., 2006; Paterson and Brock, 2007). Cooper and Jago (2007) outlined the
92 history of investigations into South Australian Cambrian biostratigraphy.

93 Subsequent biostratigraphic schemes have been based on a variety of fossil groups
94 (see reviews by Zang, 2002; Jago et al., 2006, 2012; Paterson and Brock, 2007; Kruse et al.,

2009), with separate zonations based on archaeocyaths (Walter, 1967; Gravestock 1984; Zhuravlev and Gravestock, 1994), trilobites (Jell in Bengtson et al., 1990) and acritarchs (Zang et al., 2007). In the absence of a local stage subdivision specifically for the Australian lower Cambrian, previous workers such as Gravestock and Cowley (1995), Brock and Cooper (1993), Shergold (1996), Young and Laurie (1996), Brock et al., (2000), Gravestock et al., (2001), Jago et al., (2006; 2012) and Kruse et al., (2009) have correlated the Australian lower Cambrian successions (not always very successfully) with the widely used Siberian stage subdivision (Nemakit-Daldynian, Tommotian, Atdabanian, Botoman and Toyonian) in the sense of Rozanov and Sokolov (1984).

3. AIMS and METHODS

In an attempt to fill this knowledge lacuna, a comprehensive fieldwork campaign over the last decade has resulted in systematic collection of fossiliferous, sedimentologic and geochemical samples from more than 20 separate stratigraphic sections and over 100 supplementary spot localities that, in composite, intersect the entire lower Cambrian succession in the Arrowie and Stansbury Basins. This comprehensive sampling has produced in excess of 1000 separate, stratigraphically constrained microfossil data points. Standard acetic acid leaching techniques were used to extract shelly material from the carbonates (see methods in Skovsted et al., 2012, Guo et al., 2014), that have yielded a great diversity and abundance of phosphatic, secondarily phosphatised and silicified shelly fossil groups. Microfossils were picked from dried residues using a binocular stereo microscope, and imaged with the JEOL JSM-6480LA and JEOL 7100FE Analytical Scanning Electron Microscopes in the Microscopy Unit, Department of Biological Sciences at Macquarie University.

The collected faunal data are presented in two parts – the biostratigraphic scheme herein is derived from 10 stratigraphic sections intersecting a broad suite of carbonate facies in the lower Hawker Group of the Arrowie Basin (Fig. 1). This part of the succession includes the broadly coeval Wilkawillina, Wirrapowie and Ajax limestones occurring below the regionally significant hiatus called the "Flinders Unconformity" (Gravestock and Cowley, 1995; Gravestock and Shergold, 2001) in the Arrowie Basin. Biostratigraphic analysis of the overlying succession (Mernmerna Formation and equivalents) is currently in preparation and will be published separately.

This work provides detailed fossil range data facilitating construction of a new biostratigraphic zonation of the lower Cambrian succession of South Australia (Terreneuvian, Stage 2 to Series 2, Stages 3–4). As a first step in establishing this new regional biostratigraphic framework, the aim of this paper is to formally name and define three new shelly fossil biozones (in ascending order) – the *Kulparina rostrata* Zone, the *Micrina etheridgei* Zone and the *Dailyatia odyssei* Zone. These zones can be correlated intra-basinally across a broad suite of synchronous carbonate-dominated facies represented by the Wilkawillina, Wirrapowie and Ajax limestones as well as inter-basinally with the broadly synchronous fossiliferous packages in the Stansbury and Officer Basins in South Australia, and the Amadeus Basin in the Northern Territory. They also have faunal ties with early Cambrian strata in China, Avalonia, Laurentia and Siberia.

The biozones established here are based on the most abundant, widespread (at least within the basin), readily identifiable and best preserved taxa, including tommotiids, brachiopods, molluscs, and bradoriid arthropods. The *Kulparina rostrata* Zone and part of the *Micrina etheridgei* Zone are pre-trilobitic, at least in terms of East Gondwanan trilobite occurrences (see discussion below on the correlation of Australian lower Cambrian trilobite zones with the global assemblages).

144 Though many SSF and associated taxa are now understood to have had a truly global
145 distribution, strong provincialism of many taxa (Larsson et al., 2014; Skovsted et al., 2015a,
146 2015b) and time lags between origination, dispersal and first appearance has hindered
147 application of SSF as tools for global biostratigraphic correlation (Landing et al., 2013).
148 Resolution of regional or basin-scale sequences is fundamentally important for global
149 chronostratigraphy, especially when using complementary methods such as isotope
150 chemostratigraphy. The International Commission on Stratigraphy (ICS) encourages the
151 integration of a variety of methods to independently correlate proposed chronostratigraphic
152 schemes (Remane et al., 1996). This is echoed by authors such as Geyer (2001), Landing et
153 al. (2013), Babcock et al. (2015), and Smith et al. (2014, 2015), who strongly advocate the
154 integration of independent chronostratigraphic data such as isotopic chemostratigraphy (and
155 magnetostratigraphy, where possible) with biostratigraphic schemes. Hence, samples for
156 chemostratigraphic analyses were collected alongside biostratigraphic samples with the aim
157 of integrating the biostratigraphy and lithostratigraphy with isotopic curves (for example, see
158 Zhu et al., 2006; Betts et al., 2015). This will facilitate high resolution intra-basin correlation
159 in addition to correlation between neighbouring basins (e.g. Stansbury Basin), and should
160 also contribute to efforts in global correlation of the lower Cambrian. Integration of
161 chemostratigraphic data with the biostratigraphic scheme presented here is currently in
162 progress and will be published separately.

163

164 ## 4. HAWKER GROUP - STRATIGRAPHIC REVIEW

165 The Hawker Group (Dalgarno, 1964) represents approximately 4200 m of carbonate-
166 dominated formations cropping out in broad synclinal tracts in the central part of the Arrowie
167 Basin (Fig. 1). The Hawker Group succession is represented by sequence set ∈1.0 of

168 Gravestock (1995) that now includes five disconformity-bounded sedimentary sequences
169 (Zang et al., 2004; Jago et al., 2012). The lowest Cambrian sequence, ∈1.0, consists of
170 prodeltaic and deltaic siltstones and sandstones of the Uratanna Formation, which
171 disconformably underlie Hawker Group rocks, deposited in valleys cut into the Ediacaran
172 Rawnsley Quartzite. The Uratanna Formation has limited distribution in the Arrowie Basin
173 and where it is absent, the Parachilna Formation (lowermost unit of the Hawker Group)
174 disconformably overlies the Rawnsley Quartzite (Gravestock, 1995; Zang et al., 2004; Jago et
175 al., 2012). For detailed reviews of the stratigraphy and lithology of the Hawker Group
176 succession see Dalgarno (1964), Haslett (1975), Clarke (1986a,1986b, 1986c, 1990a, 1990b),
177 Gravestock (1988), Gravestock and Cowley (1995), Zang et al. (2004), Paterson and Brock
178 (2007), and Jago et al. (2006; 2012).

179

180 4.1 Parachilna Formation and Woodendinna Dolostone (Sub-sequence ∈1.1A)

181 Sub-sequence ∈1.1A contains the lowstand to transgressive Parachilna Formation and
182 conformably overlying highstand Woodendinna Dolostone. This sequence package is
183 terminated by a disconformable surface in the Bunkers Graben and overlain by the lower
184 Wilkawillina Limestone (Mt. Mantell Member) which incises into the Woodendinna
185 Dolostone at some localities (Zang et al., 2004). Six stratigraphic sections (AJX-M, AJX-N,
186 WAR, BALC, MMT, MORO; see Fig. 12) intersect or are measured from the Parachilna
187 Formation, an iron-rich, fine- to coarse-grained, cross-bedded, quartz-rich sandstone with
188 thinly bedded siltstone or shale. The upper part of the formation is heavily bioturbated with
189 abundant *Diplocraterion parallelum* Torell, 1870; such vertical "piperock" is used by
190 Mángano and Buatois (2014) to define Cambrian Stage 2 on a global scale.

191 The Woodendinna Dolostone is a highstand systems tract with microbialites, oncolites
192 and low stromatolite bioherms deposited in shallow marine carbonate shelf to supratidal
193 settings (Haslett 1975). The unit crops out in both the WILK and 10MS-W sections in the
194 Bunkers Graben (Figs 9 and 10, respectively) and the MORO section on the eastern limb of
195 the Arrowie Syncline (see Fig. 12). The unit is pervasively dolomitised and as a result is often
196 strongly weathered and poorly outcropping and shelly fossils have not been recovered.

197

198 4.2 Lower Wilkawillina Limestone (Sub-sequence ∈1.1B)

199 Sub-sequence ∈1.1B commences with the Mt. Mantell Member of the lower
200 Wilkawillina Limestone (Clarke, 1986a), representing a shallow shelf carbonate with
201 apparent lateral facies changes that passes basinwards (eastwards) into the Wirrapowie
202 Limestone that contains the oldest known archaeocyaths in Australia (Jago et al., 2012). The
203 disconformity between the Woodendinna Dolostone (∈1.1A) and the lower Wilkawillina
204 Limestone (∈1.1B) is only manifest on shallow carbonate shelf areas and there does not
205 appear to be a corresponding break within the Wirrapowie Limestone (for instance, in section
206 CR1; Fig. 11).

207 The Mt. Mantell Member was originally defined on shallow platform successions in
208 the Bunkers Graben and Range (Clarke, 1986a) and is intersected by stratigraphic sections
209 BALC (61.56 m), MMT (20.25 m), WILK (25.0 m), and 10MS-W (33.53 m) (Fig. 12). A
210 relatively thick, equivalent package of lower Wilkawillina Limestone occurs in the eastern
211 Arrowie Syncline in the MORO section (Fig. 4). The Mt. Mantell Member is a high energy,
212 shallow platform carbonate interpreted to have been deposited above wave base (Clarke,
213 1986a, 1990a; Betts et al., 2014). In all sections, deposition of the Mt. Mantell Member is
214 strongly microbially mediated (*Renalcis* and *Epiphyton*), with limestones fabrics often

exhibiting a clotted appearance and massive outcrop style. Although transported archaeocyath fragments, laminate microbialites and stromatolites occur, no shelly fossils have been recorded from the Mt. Mantell Member.

The Hideaway Well Member conformably overlies the Mt. Mantell Member and crops out in the BALC (42.07 m), MMT (47.87 m), WILK (30.0 m), and 10MS-W (54.38 m) sections in the central Flinders Ranges, and at the MORO (59.0 m) section in the Arrowie Syncline in the north-east Flinders Ranges (Fig. 12). The Hideaway Well Member is characterised by increased abundance of archaeocyaths, both fragmentary and *in situ*, and relatively large bioherms are commonly developed in this member, with some measuring up to 100 m in lateral extent in the MORO section (Betts et al., 2014). The Hideaway Well Member represents a high-energy, shallow water carbonate environment and also preserves the oldest shelly fauna known from the Arrowie Basin.

The Winnitinny Creek Member (Clarke 1986a) of the Wilkawillina Limestone conformably overlies the Hideaway Well Member and is intersected in the BALC (94.74 m), MMT (169.29 m), WILK (145.0 m), and 10MS-W (108.76 m) sections in the Bunkers Graben and Range, and the MORO (135.0 m) and MOG (62.65 m) sections in the Arrowie Syncline (Figs 1, 12). Archaeocyaths occur throughout the Winnitinny Creek Member, though it is chiefly characterised by a very abundant and diverse shelly fauna. This assemblage includes a wide variety of brachiopods, tommotiids, helcionellid and bivalved molluscs, bradoriid arthropods, sponge spicules and rare echinoderm plates. Trilobites are also known to occur in the upper parts of the member with *Elicicola calva* Jell in Bengtson et al., 1990 described by Paterson and Brock (2007, p. 138-139, fig. 13) from the base of the MMF section in the Bunkers Range. The palaeoenvironment is interpreted to have been of lower energy compared to the preceding Hideaway Well Member, though deposition was still on the carbonate shelf (Betts et al., 2014). The Winnitinny Creek Member interfingers with

240 coeval ribbon carbonates of the Wirrapowie Limestone in the MORO and MOG sections
241 north of the Wirrealpa Hinge Zone (Fig. 1).

242 In sections on the shallow carbonate shelf in the central Flinders Ranges (Wirrealpa
243 Hinge Zone of Gravestock and Cowley, 1995), the Winnitinny Creek Member is truncated by
244 a distinctive red, karstic surface. This represents a regionally significant hiatus called the
245 "Flinders Unconformity" (FU) (James and Gravestock, 1990) that defines the top of sequence
246 package ∈1.1B in shallow shelf facies (Gravestock and Shergold 2001; Zang et al., 2004;
247 Jago et al., 2012) and separates the lower and upper Wilkawillina Limestones in the Bunkers
248 Graben (Clarke, 1986b). The FU represents a period of diachronous sub-aerial exposure and
249 erosion of the Wilkawillina Limestone in shallow shelf settings succeeded by deposition of
250 iron-rich micro-stromatolitic microbialites during a transgression event. The disconformable
251 surface does not occur (or is not apparent) in all sections, particularly those to the south
252 (10MS-W) and the north (MORO and MOG) (Fig. 12) of the Wirrealpa Hinge Zone,
253 indicating that pronounced breaks in sedimentation did not occur in all localities across the
254 Arrowie Basin (see also James and Gravestock 1990, p. 458-459).

255

256 4.3 Wirrapowie Limestone (Sequence ∈1.1)

257 The Wirrapowie and Wilkawillina Limestones are coeval carbonate facies
258 representing adjacent, interfingering platform and restricted lagoonal palaeoenvironments,
259 respectively (Haslett, 1975) (Fig.12). Lack of cross-bedding, quartz grains and other coarse
260 detrital material indicate a predominantly low energy regime, and lack of mud-cracks, halite
261 casts and other evidence of subaerial exposure indicates that the environment remained
262 consistently submerged (Haslett, 1975). There is no evidence of the disconformity separating
263 sub-sequence sets ∈1.1A and B in the Wirrapowie Limestone. Higher energy facies are

represented by occasional oolitic beds and sporadic, high energy events resulting in the deposition of intraformational conglomerates and breccias (as in the WAR section; Fig. 6). Coeval deposition of the Wirrapowie and Wilkawillina limestones is confirmed by the synchronous ranges of brachiopods, tommotiids and bradoriids in both facies.

4.4 Ajax Limestone (Sub-Sequence ∈1.1B and Sequence ∈1.2)

The Ajax Limestone (Fig. 1–3) crops out in the Mt. Scott Range in the northeast of the Arrowie Basin. The lower 110–120 m was deposited as part of systems tract ∈1.1B, broadly equivalent to the lower Wilkawillina and Wirrapowie limestones. The reddened horizon of the Flinders Unconformity is not apparent in AJX-M or AJX-N sections, and there is a transition to sequence package ∈1.2 which is truncated by a disconformity surface near the top of the AJX-M section (Fig. 2). Shallow water facies including stromatolitic boundstones dominate the lower 120 m of the AJX-M section. This is overlain by shelly fossil and archaeocyath rich nodular limestones and bioclastic limestones (Fig. 2; see also Brock et al., 2006; Skovsted et al., 2009a).

4.5 Second Plain Creek Member (Wilkawillina Limestone) and lower Mernmerna Formation (Sequence ∈1.2)

The Second Plain Creek Member of the Wilkawillina Limestone ("middle Wilkawillina Limestone" of Gravestock and Hibburt (1991) only outcrops in the Bunkers Graben (WILK, Figs. 9, 12). The Second Plain Creek Member is interpreted to have been deposited on a starved carbonate platform during rapid transgression and is transitional

between the relatively shallow facies of the Winnitinny Creek Member and the deeper outer shelf facies of the overlying Mernmerna Formation (Clarke, 1986b).

The Mernmerna Formation is subdivided into three members, from lowest to highest; the Six Mile Bore Member, the Linns Springs Member and the Third Plain Creek Member (Clarke, 1986c). The Mernmerna Formation crops out in the MMT (7.5 m) and MOG (369.8 m) sections and Bunkers Graben where WILK and 10MS-W were measured (the WILK and 10MS-W sections terminate at the boundary between the Wilkawillina Limestone and the Mernmerna Formation) (Fig. 12). The duration of the hiatus represented by the disconformity between the top of the Winnitinny Creek Member of the lower Wilkawillina limestone (Sequence ∈1.1B) and the outer shelf deposits of Mernmerna Formation (Sequence ∈1.2) is variable. Most sections on the shallow platformare missing all or large parts of the lower Mernmerna Formation due to lack of deposition (e.g. BALC, Fig. 7 and MMT, Fig. 8 sections).

The nodular limestones of the Mernmerna Formation (Sequence ∈1.2) are interpreted to have been deposited in low energy, outer shelf, ramp and slope settings (Haslett, 1975; Daily, 1976), with input of allochthonous carbonates containing slumps or slide structures (Clarke, 1990c; Gravestock, 1995) representing active shelf collapse and slope processes.

5. NEW BIOSTRATIGRAPHIC ZONES

Distinctive shelly fossil assemblages recur consistently throughout all measured sections within carbonate packages of subsequence ∈1.1B in the lower Hawker Group, and permit the establishment of three successive biozones. The *Kulparina rostrata* Zone has relatively low diversity shelly fauna, but is characterised by overlapping or partially

309 overlapping ranges of tommotiids and a paterinid brachiopod. The overlying *Micrina*
310 *etheridgei* Zone is represented by a high diversity assemblage containing a mix of
311 tommotiids, brachiopods, molluscs and arthropods. The base of the *Dailyatia odyssei* Zone is
312 broadly equivalent with the base of sequence package ∈1.2, and is formally defined, but full
313 description of the taxa associated with this zone and its regional and global correlation is
314 currently in preparation and will be published separately.

315

316 5.1 *Kulparina rostrata* Zone

317 The *K. rostrata* Zone occurs in the Hideaway Well Member and lower half of the
318 Winnitinny Creek Member of the Wilkawillina Limestone (e.g. MORO, Fig. 4; BALC, Fig.
319 7; MMT, Fig. 8; WILK, Fig. 9) and the lower 430 m of the Wirrapowie Limestone in the
320 WAR (Fig. 6) and CR1 sections (Figs. 11-12). The designated reference section is 10MS-W
321 (Fig. 10, Appendix 9). Diversity within the zone is relatively low, typically containing five or
322 six taxa including eccentrothecimorph and camenellan tommotiids and a paterinid
323 brachiopod.

324

325 5.1.1 Lower Boundary

326 The lower boundary of the *K. rostrata* Zone is defined by the first occurrence of either
327 the eccentrothecimorph tommotiid *Kulparina rostrata* Conway Morris and Bengtson *in*
328 Bengtson, Morris, Cooper, Jell and Runnegar, 1990 (Fig. 13H-N, Q) or the paterinid
329 brachiopod *Askepasma saproconcha* Topper, Holmer, Skovsted, Brock, Balthasar, Larsson,
330 Petterson Stolk and Harper, 2013 (Fig. 13A-G).

331

5.1.2 Upper Boundary

The upper boundary of the K rostrata Zone is coincident with the base of the overlying M etheridgei Zone based on the first occurrence of either *M. etheridgei* or *A. toddense*. In 10MS-W (Fig. 10) and CR1 (Fig. 11) the last occurrence of *K. rostrata* and the first occurrences of either *M. etheridgei* or *A. toddense* are in the same horizon. In all other sections, ranges of both *K. rostrata* and *A. saproconcha* are completely restricted to within the zone. The upper boundary of the *K. rostrata* Zone in all sections is located below the incoming of trilobites in East Gondwana.

5.1.3 Accessory Taxa

Accessory taxa in the *K. rostrata* Zone include the camenellan tommotiids *Dailyatia ajax* Bischoff, 1976 (Fig. 14A-G), *Dailyatia macroptera* (Tate, 1892) (Fig. 14H-K), *Dailyatia bacata* Skovsted, Betts, Topper and Brock, 2015 (Fig. 14P-S) and *Dailyatia helica* Skovsted, Betts, Topper and Brock, 2015 (Fig. 14L-O) (see also Skovsted et al. 2015). *Dailyatia ajax* and *D. macroptera* have stratigraphic ranges that extend below (e.g. BALC, Fig. 7; CR1; Fig. 11) and above the defined boundaries of the *K. rostrata* Zone. *Dailyatia bacata* and *D. helica* have first occurrences in the K. rostrata Zone but range into the overlying *M. etheridgei* Zone. The eccentrothecimorph tommotiid *Paterimitra pyramidalis* Laurie, 1986 also has a first occurrence in this zone and ranges into the overlying *M. etheridgei* and *D. odyssei* zones (Fig. 13, O-P, R-V).

Shields attributed to *Sinskolutella cuspidata* Betts, Topper, Valentine, Skovsted, Paterson, and Brock, 2014 based on distinctive dactiloscopic microornament (Fig. 19, E-H, see Betts et al. 2014, fig. 6) occur in the *K. rostrata* Zone in the MMT section; the lowest

355 known occurrence of bradoriids in the Arrowie Basin (Fig. 8, Appendix 7). However,
356 occurrence *S. cuspidata* in the *M. etheridgei* Zone (MORO and MOG sections), and
357 potentially also the *D. odyssei* Zone (unpublished data), suggests a long stratigraphic range
358 for this taxon, spanning pre-trilobitic to *P. janeae* Zone strata.

359

360 5.2 *Micrina etheridgei* Zone

361 The *Micrina etheridgei* Zone is restricted to the upper half of the Winnitinny Creek
362 Member of the Wilkawillina Limestone and temporal equivalents in the Wirrapowie and Ajax
363 limestones. Diversity within the zone is relatively high (~28 species in the AJX-M section),
364 including eccentrothecimorph and camenellan tommotiids, organophosphatic brachiopods,
365 helcionelloid molluscs, bradoriid arthropods and lobopods.

366

367 5.2.1 Lower Boundary

368 The *Micrina etheridgei* Zone is often highly fossiliferous (e.g. MMT section,
369 Appendix 7).The lower boundary is defined by the first occurrence of the tannuolinid
370 tommotiid *Micrina etheridgei* (Tate, 1892) (Fig. 15J-P) or the paterinid brachiopod
371 *Askepasma toddense* (Fig. 16A-H). *Askepasma toddense* Laurie, 1986 (Fig. 16A-H) has a
372 mutually exclusive stratigraphic range with the older (possibly ancestral) *Askepasma*
373 *saproconcha*. *Askepasma toddense* ranges from the Winnitinny Creek Member of the
374 Wilkawillina Limestone into the Second Plain Creek Member (WILK, Fig. 9) above the FU.
375 A taxon similar to *A. toddense* occurs in the *D. odyssei* Zone in the Mernmerna Formation,
376 though these are typically poorly preserved and may be reworked (MOG section,Fig. 5; Fig.
377 16C).

5.2.2 Upper Boundary

The upper boundary of the M. etheridgei Zone is coincident with the base of the overlying *D. odyssei* Zone based on the first occurrence of *Dailyatia odyssei* Evans and Rowell, 1990 or *Stoibostrombus crenulatus* Conway Morris and Bengtson in Bengtson et al., 1990. In sections measured through platformal carbonates in the central Flinders Ranges (Fig. 1) such as BALC (Fig. 7), MMT (Fig. 8), WILK (Fig. 9), 10MS-W (Fig. 10) the *M. etheridgei* Zone is capped by the regionally significant Flinders Unconformity (FU). This surface is manifest as a distinctive karstic microstromatolitic "reddened horizon" (Gravestock and Cowley 1995). The duration of this hiatus is variable across the Arrowie Basin (see also James and Gravestock 1990, p. 458-459). The duration of the unconformityin the WILK section for example, represents an unknown period of subaerial exposure and non-deposition (Fig. 9). Here, the upper boundary of the *M. etheridgei* is delineated by the karstic surface. *Micrina etheridgei* (as well as accessory taxa *Dailyatia ajax, D. macroptera, D. helica* and *D. bacata*) does not occur stratigraphically above the "reddened horizon".

5.2.3 Accessory Taxa

Shelly taxa that have first occurrences within the *M. etheridgei* Zone include a number of organophosphatic brachiopods, helcionelloid molluscs, bradoriids and lobopods, some of which have correlative potential (see below). Accessory taxa include *D. ajax, D. macroptera, D. helica* and *D. bacata* which range from the underlying *K. rostrata* Zone and terminate within the *M. etheridgei* zone.

Organophosphatic brachiopods such as *Eoobolus* spp. (which includes *Sukaharilingula* Ushatinskaya 2012), *Karathele yorkensis* Holmer and Ushatinskaya in Gravestock et al., 2001 (Popov et al., 2015, p. 32, have recently synonymized *Karathele* with *Schizopholis*), *Eodicellomus elkaniiformis* Holmer and Ushatinskaya in Gravestock et al., 2001, and *Kyrshabaktella davidi* Holmer and Ushatinskaya in Gravestock et al., 2001 (Fig. 16 I-U and Fig. 17 A-T) all have first occurrences in the *M. etheridgei* Zone, but range into the overlying *D. odyssei* Zone.

The tommotiid *Eccentrotheca helenia* Skovsted, Brock, Topper, Paterson and Holmer, 2011 (Fig. 15, A-I) first occurs in the *M. etheridgei* Zone. First appearance of *E. helenia* has been taken as a proxy for the lower boundary of the *A. huoi* Zone. This level consistently occurs above the defined lower boundary of the *M. etheridgei* Zone (Fig. 4; see also Betts et al., 2014, fig. 2), demonstrating that the lower part of the zone is pre-trilobitic.

The *M. etheridgei* Zone records the first occurrences of a number of helcionelloid molluscan taxa that range into the overlying *D. odyssei* Zone (Fig. 18). Taxa include *Pelagiella subangulata* (Tate, 1892), *Anabarella australis* Runnegar in Bengtson et al., 1990 and *Mackinnonia rostrata* (Zhou and Xiao, 1984), often preserved as steinkerns (Fig. 18). The difficulty in accurately identifying steinkern material to species level makes utilisation of these taxa problematic in biostratigraphic schemes (see also discussion by Jacquet and Brock 2015). *Pelagiella subangulata* has been suggested as a possible proxy to define the base of Series 2, Stage 3 on a global scale (see Peng et al., 2012). Whilst some steinkerns probably represent *P. subangulata* (Fig. 18A, D; AJX-M, Fig. 2, AJX-N, Fig. 3, MORO, Fig. 4, MOG, Fig. 5), we take a cautious taxonomic approach and acknowledge the difficulties of confidently identifying steinkern material to species level.

The *M. etheridgei* Zone hosts a unique assemblage of bradoriids that are restricted to the zone (~10 species) (Figs. 19, 20), key amongst these are *Liangshanella circumbolina* Topper, Skovsted, Brock & Paterson, 2011, *Quadricona madonnae* Topper, Skovsted, Brock & Paterson, 2011 (Fig. 20, E, F) and *Zepaera jagoi* Topper, Skovsted, Brock & Paterson, 2011 (Topper et al., 2011). The range of the Chinese taxon *Parahoulongdongella bashanensis* (Shu, 1990) is also restricted to the *M. etheridgei* Zone (Fig. 20, A-D). Endemic taxa include *Jiucunella phaseloa* Betts, Topper, Valentine, Skovsted, Paterson, Brock, 2014 (Fig. 19, A-D) is restricted to the *M. etheridgei* Zone. Similarly, the haoiid *Jixinlingella daimonikoa* Betts, Topper, Valentine, Skovsted, Paterson, Brock, 2014 (Fig. 19. S-U), *Mongolitubulus anthelios* Betts, Topper, Valentine, Skovsted, Paterson, Brock, 2014 (Fig. 19, M-R) and *Neokunmingella moroensis* Betts, Topper, Valentine, Skovsted, Paterson, Brock, 2014 (Fig. 19. I-L) occur only in the *M. etheridgei* Zone (MORO and MOG, Figs. 4-5). A distinctive new species of *Mongolitubulus* (Fig. 20 J-K) occurs in the *M. etheridgei* Zone in CR1/589.7 (Appendix 10) and MOG 114.1 (63.7 m true thickness from base). *Mongolitubulus* spines are abundant throughout these sections though abraded specimens are difficult to assign to species.

Other shelly fossils in the *M. etheridgei* Zone include sclerites of the lobopodian *Microdictyon* Bengtson, Matthews and Missarzhevsky in Missarzhevsky and Mambetov, 1981 (Fig. 21, T-V). The FAD of *M. effusum* may be utilised to define the base of Cambrian Series 2, Stage 3 where trilobites might be absent (Peng et al., 2012). Steiner et al., (2007) noted *Microdictyon effusum* Bengtson, Matthews and Missarzhevsky in Missarzhevsky and Mambetov, 1981 as an accessory taxon in a number of biozones subdividing lower Cambrian strata on the Yangtze Platform in South China. However, Topper et al., (2011a) suggested that the morphology of *Microdictyon* sclerites can vary intraspecifically and also along the trunk of a single animal. In the studied sections, *Microdictyon* sclerites have only been

448 recovered from AJX-M (Fig. 2), MORO (Fig. 4) and MOG (Fig. 5) and show a sporadic
449 stratigraphic distribution throughout the *M. etheridgei* Zone and into the overlying *D. odyssei*
450 Zone. This, coupled with taxonomic difficulties outlined by Topper et al., (2011a), precludes
451 the biostratigraphic application of *Microdictyon* at the specific level in the Arrowie Basin and
452 potentially elsewhere.

453

454 5.3 *Dailyatia odyssei* Zone

455 5.3.1. Lower Boundary

456 The lower boundary of the *Dailyatia odyssei* Zone is defined by the first appearance
457 of the camenellan tommotiid *Dailyatia odyssei* (Fig. 21. M-O), or the problematic
458 ecdysozoan *Stoibostrombus crenulatus* (Fig. 21. H-L). *Dailyatia odyssei* has a stratigraphic
459 range that is younger and, importantly, does not overlap the range of any other *Dailyatia*
460 species in South Australia (AJX-M, Figs 2, MOG, Fig. 5, WILK, Fig. 9). In the AJX-M
461 section, *D. odyssei* occurs in the uppermost 3.4 m of the *A. huoi* trilobite Zone (Fig. 2;
462 Appendix 1). However, *D. odyssei* has a long stratigraphic range encompassing the *Pararaia*
463 *tatei*, *P. bunyerooensis* and lowermost part of the *P. janeae* trilobite zones (Skovsted et al.,
464 2015a).

465 In MMT (Fig. 8), the Flinders Unconformity represents an unknown period of
466 subaerial exposure and non-deposition. The presence of the *D. odyssei* Zone is indicated by
467 the occurrence of *Stoibostrombus crenulatus* but does not represent the true base of the zone
468 due to the FU. In MMT, the Third Plain Creek Member of the Mernmerna Formation (*P.*
469 *bunyerooensis* trilobite Zone) rests directly on the Winnitinny Creek Member of the
470 Wilkawillina Limestone. Hence, the Six Mile Bore and Linns Springs members of the

471 Mernmerna Formation are missing in the MMT (Fig. 8) section and the true lower boundary
472 of the *D. odyssei* Zone cannot be accurately ascertained.

473 The FU also obscures the relationship between the *M. etheridgei* and *D. odyssei* zones
474 in WILK (Fig. 9). Here, the incoming of both *D. odyssei* and *S. crenulatus* is in the same
475 horizon in the Second Plain Creek Member (RS337/A), the first sample taken
476 stratigraphically above the FU. However, increased sampling between the samples directly
477 above and below the disconformity surface, would more clearly define the boundaries.
478 Additionally, in the BALC section (Fig. 7) the entire Mernmerna Formation (and therefore
479 the *D. odyssei* Zone) is completely absent due to lengthy hiatus at the FU (Fig. 22).

480

481 5.3.2. Accessory Taxa

482 Common taxa in the lower part of the *D. odyssei* Zone include tommotiids,
483 stoibostrombids, brachiopods and bradoriids (Figs. 19-21). The tommotiid *Lapworthella*
484 *fasciculata* Conway Morris and Bengtson in Bengtson et al., 1990 (Fig. 21A-G, K) has a first
485 occurrence in the underlying *M. etheridgei* Zone, but ranges up into the *D. odyssei* Zone
486 where it can be very abundant (e.g. WILK section, Appendix 8). *Paterimitra pyramidalis* also
487 ranges into the *D. odyssei* Zone from the *K. rostrata* Zone. Other problematic microfossils
488 associated with the *D. odyssei* Zone include *Protohertzina* sp. and *Mongolodus* sp. spines
489 (Fig. 21W, X).

490 Brachiopods in the *D. odyssei* Zone include *Eoobolus* spp., *Karathele yorkensis*,
491 *Kyrshabaktella davidii, Eodicellomus elkaniiformis*, *Minlatonia tuckeri* Holmer and
492 Ushatinskaya in Gravestock et al., 2001 (Figs 16I-U and 17A-T) which range up from the *M.*
493 *etheridgei* Zone. Other shelly taxa in the *D. odyssei* Zone include *Mickwitzia* sp. an

494 undescribed new genus of organophosphatic brachiopod (Fig. 21P-R). Helcionelloid molluscs
495 such as *Mackinnonia* Runnegar in Bengtson et al., 1990 (Fig 18N-U), *Anabarella* Vostokova,
496 1962 (Fig. 18I-M) and *Pelagiella* Matthew, 1895 (Fig. 18A-H) and bradoriids are also
497 abundant in the *D. odyssei* Zone, with many ranging up from the underlying *M. etheridgei*
498 Zone.

499

500 ## 6. CORRELATION IN EAST GONDWANA

501 The new shelly fossil biozones defined here can be correlated across the Arrowie
502 Basin and with neighbouring depocentres such as the Stansbury, Officer, Amadeus and
503 Georgina basins.

504

505 ### 6.1 Arrowie Basin

506 The oldest faunal assemblage (FA1) reported by Daily (1956) was based on shelly
507 material from the Flinders Ranges (Mt. Scott Range, Lake Frome and Wilson-Quorn areas).
508 This archaeocyath-rich assemblage also contains a single unidentified organophosphatic
509 ("atrematous") brachiopod (Daily 1956, p. 129). Daily's FA1 appears to largely overlap with
510 the *K. rostrata* Zone based on a rich archaeocyath fauna and low diversity shelly fauna (see
511 Fig. 22).

512 Daily (1956) noted that *Micromitra* (*Paterina*) *etheridgei* (=*Micrina etheridgei*
513 Laurie, 1986) was abundant in his faunal assemblage 2 (FA2). In the new biostratigraphic
514 scheme, we recognise the importance of *M. etheridgei* as a key faunal indicator and use it to
515 define the *M. etheridgei* Zone. In addition, Daily (1956) also noted the presence of

516 *Ambonychia macroptera* in FA2, now identified as the tommotiid species *Dailyatia*
517 *macroptera* (see Skovsted et al., 2015a), which first appears in the *K. rostrata* Zone and
518 ranges into the overlying *M. etheridgei* Zone. The brachiopod *Kutorgina peculiaris* (Tate,
519 1892) was also noted by Daily (1956) in FA2. *Askepasma saproconcha* may have been
520 misidentified as *K. peculiaris* by Daily (1956), which also has a relatively large sulcate shell
521 (see Walcott, 1912, pl. V, fig. 2), suggesting Daily's FA2 may partially overlap the *K.*
522 *rostrata* Zone and the *M. etheridgei* Zone.

523 Daily's (1956) FA3 and FA4 are trilobite-rich, and include helcionellids and hyoliths.
524 Jell in Bengtson et al., (1990, p.15) correlated Daily's FA3 with the *A. huoi* Zone based on
525 the occurrence of *Yorkella australis* Woodward, 1884 and *Abadiella huoi* Chang, 1966 (see
526 also Paterson and Brock, 2007). Daily's FA4 correlates with the *P. tatei* Zone based on the
527 occurrence of the eponym (Daily 1956, p. 130; Jell in Bengtson et al., 1990, p.15). Daily's
528 (1956) FA3 and FA4 are therefore likely to correlate with the upper *M. etheridgei* Zone and
529 the *D. odyssei* Zone, respectively. Correlation of Daily's (1956) faunal assemblages 1–4 with
530 the new biozones is shown in Figures 22 and 23.

531 Trilobites are currently the most readily utilised biostratigraphic tool for defining a
532 lower Cambrian biozonation in Australia. Jell in Bengtson et al., (1990) initially erected four
533 trilobite biozones – (from oldest to youngest): *Abadiella huoi*, *Pararaia tatei*, *P.*
534 *bunyerooensis*, and *P. janeae*. Paterson and Brock (2007) described a new faunal assemblage
535 within the *P. bunyerooensis* Zone in the Bunkers Range and recognised a close faunal
536 connection between the trilobites of South Australia and South China for this time interval.
537 They also noted that the first appearance of trilobites in the Arrowie Basin, including the
538 eponym of the oldest trilobite zone, *Abadiella huoi*, occurs in the upper half of the
539 Winnitinny Creek Member of the Wilkawillina Limestone and equivalent strata in the Ajax

Limestone. The first appearance of *A. huoi* always occurs above the base of the *M. etheridgei* Zone as defined here, though the zones overlap. The upper boundary of the *A. huoi* Zone, best expressed in the AJX-M section, occurs 12 m stratigraphically above the top of the *M. etheridgei* Zone where it overlaps with the lower boundary of the *D. odyssei* Zone (Fig. 2).

6.2 Stansbury Basin

The early Cambrian shelly fauna of the Stansbury Basin have been relatively well studied. However, much of the taxonomic syntheses that underpin these early biostratigraphic investigations (Bengtson et al., 1990; Gravestock et al., 2001) predate extensive modern systematic treatments of key shelly fossil taxa from South Australia (see references herein). The result is that it can be difficult to tease out the true biostratigraphic signals from these monographs. Ultimately, only recollection of fossil material along measured stratigraphic sections will resolve uncertainties in correlation with the Arrowie Basin.

6.2.1 Small Shelly Fossils

Gravestock et al., (2001) established three shelly fossil zones (from oldest to youngest): *Hippopharangites dailyi*, *Halkieria parva* and *Kaimenella reticulata*. However, the *Hippopharangites dailyi* and *Halkieria parva* biozones are based on taxa with poorly understood multi-element scleritomes. Meagre illustrations of these species do not show all sclerite types for each taxon, hindering meaningful taxonomic comparisons and their biostratigraphic utility. Additionally, inconsistencies in the definitions of these zones have prevented their widespread application.

562 *Kulparina rostrata* as originally described by Bengtson et al., (1990) is entirely
563 restricted to the upper part of the Kulpara Limestone at Horse Gully (= type locality).
564 Skovsted et al., (2011b, p. 281; see also Skovsted et al., 2015b) noted that the specimens
565 originally described as *Eccentrotheca guano* Bengtson in Bengtson et al., (1990, p. 119-120,
566 fig 71-73) from the Kulpara Limestone are actually sclerite morphotypes of *K. rostrata*. All
567 figured specimens of *K. rostrata* (Bengtson et al., 1990, Figs 71-73, 86-90) are derived from
568 two samples (6429RS103 and UNEL1858) located 8.0 m and 7.5 m, respectively, below the
569 disconformity between the Kulpara and Parara limestones. Re-examination of sample
570 6429RS104, 3.0 m below the disconformity in the upper Kulpara Limestone at Horse Gully
571 contains abundant *K. rostrata* along with *Dailyatia ajax, D. macroptera, D. bacata* and many
572 fragments of a paterinid brachiopod, attributable to *Askepasma saproconcha*. The occurrence
573 of *K. rostrata* cannot be confirmed above sample 6429RS104 (see Bengtson et al., 1990, fig.
574 4). Hence, the *K. rostrata* Zone occurs in a ~5.0 m interval between samples 6429RS103 and
575 6429RS104 in the Kulpara Limestone. The low diversity fauna in this interval also accords
576 with typical assemblages of the *K. rostrata* Zone in the Arrowie Basin.

577 Gravestock et al., (2001, fig.11) also reported the presence of *Kulparina* cf. *rostrata*
578 in the lower Parara Limestone in the SYC-101 drillcore, located 25 km south of Horse Gully.
579 None of this material was figured, however the fact that the taxon co-occurs with a
580 moderately high diversity shelly assemblage in the lower Parara Limestone, strongly suggests
581 that the specimens are not *K. rostrata*. Thus, there is no definitive evidence that *K. rostrata*
582 has a range that extends above the Kulpara Limestone on Yorke Peninsula.

583 Sample 6429RS105, located 1.0 m below the disconformity horizon at Horse Gully
584 (see Bengtson et al., 1990, fig. 4), contains a high diversity shelly assemblage (15+ taxa)
585 including *Micrina etheridgei*, *Dailyatia ajax*, *D. macroptera*, numerous hyoliths, spicules,
586 hyolithelminth tubes, *Sinosachites delicatus* (Jell, 1981), *Hippopharangites dailyi* Bengtson

in Bengtson et al., 1990 and *Eremactis* spp. Indeterminate paterinid fragments are also present. This suggests the *M. etheridgei* Zone is restricted to a ~1.0 m interval directly beneath the disconformity surface. Importantly, whilst *M. etheridgei* is reported in samples immediately above the disconformity at Horse Gully by both Bengtson et al., (1990; sample 6429RS106) and Gravestock et al., (2001; samples HG0 and HG1) there is no record of *D. ajax*, *D. macroptera*, *D. bacata* or *D. helica* above the disconformity.This suggests that the disconformity surface in the western Stansbury Basin (at least at Horse Gully) may record a significantly longer hiatus than the Flinders Unconformity on platform successions in the Arrowie Basin. Both the *K. rostrata* Zone and the *M. etheridgei* Zone are represented by a very narrow (possibly condensed) interval at Horse Gully.

The Parara Limestone succession overlying the disconformity surface at the Horse Gully section contains a very diverse shelly fauna including halkieriids, hyoliths, *Microdictyon*, bradoriids and the micromolluscs *Mackinnonia*, *Pelagiella* and *Anabarella*. This level also contains *Stoibostrombus crenulatus* (in sample 6429RS106) and the trilobite *Yorkella australis* (Jell in Bengtson et al., 1990), confirming that the lower part of the Parara Limestone at Horse Gully correlates with the *D. odyssei* Zone in the Arrowie Basin (Fig. 22).

Stoibostrombus crenulatus is also reported in the Parara Limestone in SYC-101, CD-2, and Port Julia-1A sections where it occurs with typical *D. odyssei* Zone taxa, such as the helcionelloid molluscs *Mackinnonia rostrata* and *Pelagiella subangulata* and a wide variety of brachiopods such as *Eoobolus* sp., *Minlatonia tuckeri* and *Eodicellomus elkaniiformis*. The tannuoliniid *Micrina etheridgei* is also present in HG1 (Parara Limestone) in Horse Gully. Gravestock et al., (2001, Fig. 4) reported occurrences of *Dailyatia ajax* in the Parara Limestone above the disconformity surface (HG1 and HG9), but none of the specimens are illustrated and re-collection and detailed examination of samples through this interval of the Parara Limestone reveal that *Dailyatia* is completely absent.

612 In the eastern Stansbury Basin, a measured section through the Sellick Hill Formation
613 and Fork Tree Limestone on Fleurieu Peninsula was measured by T. Brougham (2009,
614 unpublished Honours thesis) and by MJB, JBJ, SMJ and GAB (2013, unpublished data). The
615 tommotiid taxon *Sunnaginia imbricata* Missarzhevsky, 1969 was recovered from horizons
616 within Facies E (*sensu* Alexander and Gravestock 1990) in the upper Sellick Hill Formation
617 (Fig. 22). *Sunnaginia* Missarzhevsky, 1969 was widely dispersed during the early Cambrian,
618 with occurrences recorded in Siberia, Mongolia, Avalonian North America, and the United
619 Kingdom (Murdock et al., 2012), but this taxon has not been recovered from the Arrowie
620 Basin. In the upper Sellick Hill Formation, *S. imbricata* co-occurs with *Dailyatia ajax*,
621 *Kulparina rostrata* and a probable new species of *Askepasma*. Typical elements of the *K.*
622 *rostrata* Zone including *D. ajax*, *D. macroptera* and *K. rostrata* occur throughout the
623 overlying Fork Tree Limestone. The presence of taxa indicative of the *K. rostrata* Zone at the
624 top of the Fork Tree Limestone suggests that this unit is older than previously thought and
625 likely correlates with the Hideaway Well and Winnitinny Creek members of the Wilkawillina
626 Limestone in the Arrowie Basin. The lack of trilobites from outcrop in the Fork Tree
627 Limestone supports this correlation. The typically diverse *M. etheridgei* Zone shelly fauna,
628 including the eponym, is absent in the overlying Heatherdale Shale (apart from one specimen
629 collected in a loose nodule; Alexander and Gravestock 1990) (Fig. 22).This may indicate a
630 cryptic disconformity between the Fork Tree Limestone and the Heatherdale Shale (that latter
631 containing *P. janeae* Zone trilobites, e.g., *Atops* Emmons, 1844 (Jago et al., 1984) towards
632 the top of the unit). If this were the case, the *M. etheridgei* Zone would be largely missing in
633 the eastern Stansbury Basin. Alternatively, the deep water slope facies of the Heatherdale
634 Shale may record relatively slow continuous basinal depositional cycles in environments that
635 are devoid of the shelf-dominated shelly fauna that define the *M. etheridgei* Zone.

636

637 6.2.2 Molluscs

638 Early Cambrian molluscs and their biostratigraphic applications have been widely
639 studied (Demidenko, 1999, Parkhaev, 2000, 2001, Parkhaev in Gravestock et al., 2001). In
640 addition to the small shelly fossil scheme, Gravestock et al., (2001) established four informal
641 molluscan zones based mostly on Stansbury Basin material (oldest to youngest): the
642 *Pelagiella subangulata*, *Bemella communis*, *Stenotheca drepanoida*, and *Pelagiella*
643 *madienesis* zones. Micromolluscan taxa typical of the *M. etheridgei* Zone in the Arrowie
644 Basin include *Pelagiella subangulata*, *Anabarella australis*, *Mackinnonia rostrata* and
645 *Pojetaia runnegari* Jell, 1980 in the Ajax and Wilkawillina limestones. This molluscan
646 assemblage, in particular the occurrence of *P. subangulata* and *M. rostrata*, broadly
647 correlates the *M. etheridgei* Zone with the *Pelagiella subangulata* Zone of Gravestock et al.,
648 (2001) in the Stansbury Basin, though the latter zone is poorly defined.

649 The *Bemella communis* Zone of Gravestock et al., (2001) is very problematic due to
650 the poorly constrained biostratigraphic range and potentially flawed taxonomy of the
651 eponym, thwarting correlation between basins. The stratigraphic range of *B. communis* on
652 Yorke Peninsula is restricted to the lower Parara Limestone, which is approximately
653 equivalent (based on typical *D. odyssei* Zone fauna – see above) with the lower Mernmerna
654 Formation in the Arrowie Basin. However, in the Sellick Hill Formation on Fleurieu
655 Peninsula, the stratigraphic range of *B. communis* ranges below the *Pelagiella subangulata*
656 Zone, preceding the first occurrence of *Sunnaginia imbricata* and *Kulparina rostrata*. This
657 very low stratigraphic occurrence of *Bemella communis* potentially compromises the
658 biostratigrpahic utility of this taxon, or at least suggests a detailed revision of this and similar
659 species is required. Furthermore, Gravestock et al., (2001) identified '*B. communis*' in the
660 Mernmerna Formation of the Mulyungarie-2 core in the far eastern part of the Arrowie Basin,
661 but this material was not figured, so the identification cannot be verified.

662 Early Cambrian molluscs are often exceedingly abundant; however, their taxonomy
663 has been plagued by problems of preservation. Steinkerns are very common, but are often not
664 sufficient for classification and therefore should be used with extreme caution in detailed
665 biostratigraphic work. The difficulties associated with early Cambrian mollusc taxonomy and
666 preservation has implications for the widespread use of molluscan taxa such as *P.*
667 *subangulata* as indicators of major stratigraphic boundaries (Peng et al., 2012). Hence, in the
668 current scheme they are relegated to accessory taxa.

669

670 6.2.3 Archaeocyaths

671 Archaeocyaths from Horse Gully on Yorke Peninsula were initially used by Etheridge
672 (1890) to establish a Cambrian age for these limestones in South Australia and were the first
673 group to undergo rigorous biostratigraphic treatment (Walter, 1967). Extensive systematic
674 and biostratigraphic works (Kruse and West 1980; Gravestock, 1984, Zhuravlev and
675 Gravestock, 1994) have established regional archaeocyathan biozones (Peng et al., 2012). Yet
676 there are undoubted taxonomic difficulties. For example, Zhuravlev and Gravestock (1994)
677 demonstrated that a single archaeocyath taxon (*Archaeopharetra irregularis* Taylor, 1910)
678 may be confused with up to six other taxa throughout ontogeny. Identification complications
679 along with high levels of endemism impede their applicability for global-scale
680 biostratigraphic correlation.

681 A biostratigraphic scheme based on archaeocyaths from the Flinders Ranges (i.e.,
682 Wilkawillina Gorge and the Mt. Scott Range) was produced by Gravestock (1984) and later
683 updated with material from Yorke Peninsula (Stansbury Basin) by Zhuravlev and Gravestock
684 (1994). The sections in the Flinders Ranges intersect the lowermost Wilkawillina and Ajax
685 limestones and contain highly diverse archaeocyathan taxa. Gravestock (1984) recognised

two major assemblages, Faunal Assemblages I and II and three younger (minor) assemblages, III, IV and V; IV and V are only found in the Mt. Scott Range. Faunal Assemblage II was further subdivided into upper and lower parts (Fig. 22).

The oldest assemblage (Faunal Assemblage I) contains a maximum of 10 archaeocyath taxa, but only *Copleicyathus cymosus* Gravestock, 1984 and *Warriootacyathus wilkawillinensis* Gravestock, 1984 are restricted to this zone and are found in both the Wilkawillina and Ajax Limestone sections. At Wilkawillina Gorge, the incoming of archaeocyaths occurs in the lowermost Mt. Mantell Member, below a distinctive 10 m thick unfossiliferous ooid grainstone. The lower boundary of the *K. rostrata* Zone in the WILK section occurs in the basal Hideaway Well Member, ~20 m above the base of Gravestock's Faunal Assemblage I and so the two zones have ~ 30 m of overlap through the Hideaway Well Member (Fig. 22).

Gravestock (1984, p. 3) noted the presence of minor shelly fossils such as a 'large' *Kutorgina* sp. (which is most likely to be *Askepasma saproconcha*), in addition to hyoliths and chancelloriids in Faunal Assemblage 1. Gravestock (1984) does not report any supplementary shelly fossils from his Lower Faunal Assemblage II, but the boundary between Faunal Assemblages I and II is reported to contain a fossiliferous band with *Chancelloria* Walcott, 1920 and the bivalve mollusc "*Fordilla"* Barrande, 1881 (most likely to be *Pojetaia runnegari*, as *Fordilla* is unknown from Australia.

The *M. etheridgei* Zone is broadly correlated here to Gravestock's (1984) Lower and Upper Faunal Assemblage I (Fig. 22). The upper boundary of Faunal Assemblage II terminates at the Flinders Unconformity (Wilkawillina Gorge). In Wilkawillina Gorge, *Micrina etheridgei* is noted up to 30 m above the unconformity, but below the Mernmerna Formation (referred to as the Parara Limestone by Gravestock 1984). This section must

represent the Second Plain Creek Member of the Wilkawillina Limestone, as it is the only member of the Wilkawillina Limestone deposited post-Flinders Unconformity and it is restricted to the Bunkers Graben (Clarke, 1986b). Gravestock (1984) notes the presence of a variety of brachiopods and *Lapworthella*, suggesting either *M. etheridgei* Zone or perhaps lower *D. odyssei* Zone.

Zhuravlev and Gravestock (1994) updated the original archaeocyath scheme of Gravestock (1984) and proposed three formal zones (from oldest to youngest): the *Warriootacyathus wilkawillensis*, *Spirillicyathus tenuis* and *Jugalicyathus tardus* Assemblage Zones. Importantly, these zones were based on Stansbury Basin material, utilising many of the stratigraphic sections that were later used to construct the SSF scheme of Gravestock et al., (2001). The *Warriootacyathus wilkawillensis* Zone can be approximately correlated with the *K. rostrata* Zone, as it is essentially similar to archaeocyath FA I of Gravestock (1984), and was correlated with Daily's Faunal Assemblage 1 (Zhuravlev and Gravestock, 1994). The overlying *Spirillicyathus tenuis* Zone includes archaeocyaths and accessory SSF that correlate it with Gravestock's (1984) Lower Assemblage II and the lowermost parts of Daily's (1956) Faunal Assemblage 2. The youngest zone, the *Jugalicyathus tardus* Zone, is best represented in the Flinders Ranges and is approximately equivalent to Gravestock's (1984) Upper Assemblage II, and slightly overlaps the *A. huoi* trilobite Zone. These younger archaeocyath zones are equivalent to the *M. etheridgei* Zone. The Flinders Unconformity caps the *Jugalicyathus tardus* Zone in the Flinders Ranges. Strata above this zone contain SSF and trilobites such as *Pararaia tatei* (Woodward, 1884) and *P. bunyerooensis* Jell in Bengtson et al., 1990, but no archaeocyath zones are defined (Zhuravlev and Gravestock, 1994). Zhuravlev and Gravestock (1994) identify two younger intervals with recognisable archaeocyaths; the *Syringocnema favus* beds and the *Archaeocyathus abacus* beds, which correlate with the *D. odyssei* Zone.

735

736 6.2.4 Acritarchs

737 One of the potential advantages of acritarch biostratigraphy in the Arrowie Basin is
738 that taxa have been retrieved from the lowest siliciclastic strata such as the Uratanna and
739 Parachilna formations, as well as thin shale beds within the Woodendinna Dolostone that do
740 not preserve shelly fossils. However, like archaeocyaths, difficulties with the systematics of
741 acritarchs sometimes confound confident identification of biozones (see discussion by
742 Khomentovsky and Karlova, 1993). Biostratigraphic zonation of early Cambrian acritarchs
743 from South Australia was developed by Zang in Gravestock et al., (2001), Zang et al., (2001),
744 and Zang et al., (2007). Seven acritarch assemblage zones have been developed for the lower
745 Cambrian of South Australia (Zang et al., 2007), ranging from the latest Ediacaran,
746 throughout the lower Cambrian (Terreneuvian–Series 2) to the Series 3, Stage 4–5 boundary.
747 Acritarch Zones 1, 2 and 3 encompass pre-shelly units (Uratanna and Parachilna formations).

748 The acritarch biozonation established by Zang et al., (2007) is a composite scheme
749 based on material from both the Stansbury and Arrowie basins. However, because these
750 coeval basins were deposited under different depositional regimes it is not always easy to
751 recognise and correlate these zones. For example, acritarchs from Assemblage Zone 4
752 (*Skiagia ornata* Zone) are known from the lower Kulpara Limestone (Stansbury Basin),
753 while Assemblage Zone 5 (*Skiagia ciliosa-Corollasphaeridium aliquolumum* Zone) is based
754 on material from the Wilkawillina Limestone in the Arrowie Basin. Despite being based on
755 Stansbury Basin material, Assemblage Zone 4 (*Skiagia ornata* Zone) ranges from the upper
756 parts of the Woodendinna Dolostone to the lower Wilkawillina Limestone (*A. huoi* Zone) in
757 the Arrowie Basin (Zang et al., 2007, fig. 18, pg.166), therefore encompassing pre-shelly
758 strata, in addition to the *K. rostrata* Zone and potentially also part of the *M. etheridgei* Zone.

759 The lower and upper boundaries of Acritarch Zone 4 in the Arrowie Basin are poorly
760 constrained due to a lack of detailed sampling in the interval between Zones 4 and 5 (Zang et
761 al. 2007).

762 Acritarch Assemblage Zone 5 (*Skiagia ciliosa-Corollasphaeridium aliquolumum*
763 Zone) occurs in the lower Wilkawillina Limestone (Yalkalpo-2 drillcore, 782.7-732.3 m;
764 Zang et al., 2007). Zang et al., (2007) report *Micrina etheridgei*, *Dailyatia* (species not
765 identified) and *A. huoi* from Assemblage Zone 5, therefore correlating it with Faunal
766 Assemblage 2 of Daily (1956), the *Jugalicyathus tardus* Zone of Zhuravlev and Gravestock
767 (1994), and the *M. etheridgei* Zone of the present study.

768

769 6.3 Officer Basin

770 In contrast to the richly bioclastic carbonates in the Arrowie Basin, the depositional
771 regime in the Officer Basin during the early Cambrian was dominated by mixed siliciclastics
772 with carbonates and evaporites (Gravestock, 1995). The few early Cambrian shelly fossils
773 described from the Officer Basin are known only from drill cores through the Ouldburra
774 Formation (Gravestock et al., 1997). The Ouldburra Formation and the coeval Relief
775 Sandstone were deposited as part of sequence tracts ∈1.1 to ∈1.3 that are broadly coincident
776 with the entire Hawker Group in the Arrowie Basin (Gravestock and Hibburt 1991;
777 Gravestock, 1995).

778 The Manya-6 drill core (Ouldburra Formation) has yielded cranidia and librigenae of
779 the redlichiid trilobite *Abadiella officerensis* Jago and Dunster, 2002 between 967.7–970.13
780 m depth (Jago et al., 2002a). Additional trilobite fragments were recovered from an interval
781 between 889–1263 m in this core suggesting an age no older Cambrian Stage 3. The oldest

782 fossils in this core are indeterminate sponge spicules (at 1391 m) (Gravestock et al., 1997).
783 Archaeocyath-microbial build-ups also occur in the interval 399–654 m in the Marla-6 drill
784 core which yielded hyoliths, sponge spicules and "ostracods" (probably bradoriids)
785 (Gravestock et al., 1997, p. 94).

786 Poor preservation of most fossil material from the early Cambrian of the Officer
787 Basin makes precise biostratigraphic correlation with the Arrowie Basin difficult. However,
788 the occurrence of *Abadiella officerensis* may correlate with the occurrences of the congeneric
789 *A. huoi* in the Arrowie Basin. Zang et al. (2007) also reported acritarchs from the *Skiagia*
790 *ciliosa-Corollasphaeridium aliquolumum* Zone (acritarch Assemblage Zone 5) from the
791 Manya-6 drillcore, suggesting that this part of the succession may be broadly correlated with
792 the *M. etheridgei* Zone or possibly the *D. odyssei* Zone in the Arrowie Basin.

793

794 6.4 Amadeus Basin, Northern Territory

795 The lower Cambrian Todd River Dolostone in the Amadeus Basin, central Australia is
796 richly fossiliferous (Wells et al., 1967). The unit consists of thinly bedded calcareous
797 sandstones interbedded with thin dolostone beds (Laurie and Shergold, 1985). Early
798 investigation into the shelly fauna from the Todd River Dolostone revealed archaeocyaths
799 associated with "*Micromitra etheridgei*" (=*Micrina etheridgei*) in the lower parts of the unit
800 (Wells et al., 1967). Hyoliths, brachiopods and trilobite fragments were noted in upper
801 stratigraphic levels (Wells et al., 1967; Wells et al., 1970; Laurie, 1986).

802 The Todd River Dolostone type section (and cores 25, 26 and Rodinga 5 drilled by the
803 Bureau of Mineral Resources) produced a rich fauna including *Dailyatia ajax*, *Micrina*
804 *etheridgei*, *Eccentrotheca* sp., chancelloriid spicules, *Sachites* sp., *Thambetolepis* Jell 1981 (=

Sinosachites) sp., *Edreja* Koneva 1979 (=*Eodicellomus*) sp., *Lingulella* sp., *Pelagiella* sp., indeterminate trilobites, and other indeterminate shelly fossils (Laurie and Shergold, 1985). A nearby locality (NT600) also produced a well preserved fauna described by Laurie (1986). This material included both mitral and sellate sclerites of *M. etheridgei* (Laurie, 1986). This locality also produced well preserved *Dailyatia* specimens; material figured by Laurie (1986) depicts *D. ajax* sclerites (Laurie, 1986, fig. 6A-I, 7A, C, D, F). The fauna also includes other tommotiids such as *Paterimitra pyramidalis* and *Eccentrotheca* cf. *kanesia* Landing, Nowlan and Fletcher, 1980 (later identified as probable L sclerites of *P. pyramidalis* by Larsson et al., [2014]), and another kennardiid species, *Kennardia reticulata* Laurie, 1986.

A single shell attributed to *Pelagiella* sp. was recovered from NT600 in the Todd River Dolostone, in addition to a brachiopod fauna that includes *Askepasma toddense* Laurie, 1986, *Edreja* aff. *distincta* Koneva, 1979 (= *Eodicellomus* sp.) and *Lingulella* (=*Eoobolus* spp.). This combination of taxa, in particular the presence of *Micrina etheridgei*, *Eccentrotheca*, *Askepasma toddense* and additional lingulid brachiopods enables confident correlation between the Todd River Dolostone and the *M. etheridgei* Zone age strata in the Arrowie Basin.

6.5 Georgina Basin, Northern Territory and Queensland

The Red Heart Dolostone in the Georgina Basin is broadly coeval with the Todd River Dolostone in the Amadeus Basin (Laurie and Shergold, 1985). The BMR Hay River 1lB core intersected 9.8 m of Red Heart Dolostone and yielded a phosphatic shelly fauna that included *Dailyatia ajax*, chancelloriids and *Edreja*-like (= *Eodicellomus* sp.) brachiopods and ?*Ramenta* sp. (Laurie and Shergold, 1985). A diverse fauna, including *Dailyatia ajax*, ?*Tannuolina etheridgei* (=*Micrina etheridgei*), ?*Edreja* sp., *Paterina* sp., *Lingulella* sp.,

829 indeterminate orthid brachiopods, micromolluscs such as *Yochelcionella* sp., hyoliths,
830 echinoderm fragments and chancelloriids, was also recovered from the Errarra Formation
831 (Mopunga), which was synonymised with the Red Heart Dolostone(Laurie and Shergold,
832 1985; Dunster et al., 2007). This shelly assemblage, particularly the occurrence of *M.*
833 *etheridgei*, correlates the Red Heart Dolostone with strata encompassing the *M. etheridgei*
834 Zone in the Arrowie Basin.

835

836 ## 7. CORRELATION OUTSIDE AUSTRALIA

837 The difficulties surrounding global correlation of lower Cambrian pre-trilobitic strata
838 based on SSF occurrences have been well documented (see Steiner et al., 2004, 2007;
839 Landing et al., 2013), and are largely due to faunal provincialism and facies dependence of
840 many key taxa. Therefore, high resolution correlation of this scheme outside of East
841 Gondwana is problematic. The aim of this contribution has been to establish a workable
842 regional biostratigraphic scheme. Various faunal elements (mostly at genus level) from the
843 South Australian shelly biozones have been identified that link the successions most closely
844 to strata in China (Fig. 23).

845

846 ### 7.1 *Kulparina rostrata* Zone

847 The low diversity fauna of the *K. rostrata* Zone are highly endemic, which limits
848 correlation outside of East Gondwana. However, in the Stansbury Basin, *Kulparina rostrata*
849 partially overlaps with the tommotiid *Sunnaginia imbricata* over a relatively short interval
850 (2.5 m) in Facies D of the upper Sellick Hill Formation (unpublished data), providing
851 potential global correlation for the lower part of the *K. rostrata* Zone. *Sunnaginia* has a wide

852 distribution in the early Cambrian, with previous reports from lower Cambrian strata in
853 England, Siberia, Avalonian North America and Mongolia (see Murdock et al., 2012 and
854 references therein). However, *Sunnaginia* has not been recovered from the Arrowie Basin,
855 possibly due to a lack of suitable facies.

856

857 7.2 *Micrina etheridgei* Zone

858 In China, the *S. flabelliformis-T. zhangwentangi* Assemblage Zone is succeeded by
859 the *Parabadiella huoi* trilobite Zone which correlates directly with the *A. huoi* Zone in South
860 Australia (Jago et al., 2002b; Paterson and Brock, 2007). Whilst there is continued debate
861 about the generic assignment of this species (see Landing et al., 2013 for discussion), there is
862 general agreement that *A. huoi* and *P. huoi* are conspecific. Hence, there is strong correlation
863 between the trilobitic upper part of the *M. etheridgei* Zone and the *P. huoi* zone in China.
864 Traditionally, the *A. huoi* Zone is considered to be younger than the *Profallotaspis* and
865 *Fallotaspis* zones in Siberia (see Peng et al., 2012, fig. 19.3; Landing et al., 2013, fig. 4),
866 though Yuan et al., (2011) indicated the *Parabadiella* Zone in China can be interpreted as
867 time-equivalent to the *Eofallotaspis* Zone in Morocco and the *Profallotaspis jakutensis* Zone
868 in Siberia. The correlation chart of Landing et al., (2013, fig. 4) indicates *Fallotaspis bondoni*
869 (Neltner and Poctey 1950) from southern Morocco is late Issendalenian (*Choubertella*–
870 *Daguinaspis* Zones) in age, which is ~519 Ma (Peng et al., 2012, fig. 19.11). The *Abadiella*
871 *huoi* (= *Parabadiella*) Zone is lower Nangaoan (= upper Atdabanian, *sensu* Landing et al.,
872 2013), which is therefore slightly younger (ca. 518 Ma) (Peng et al., 2012, fig. 19.11).
873 Therefore, *Abadiella* and *Fallotaspis* Hupe, 1953 may well have been contemporaneous, but
874 occurring in different trilobite provinces (see Fig. 23).

In South China, the first appearance of *Micrina xiaotanensis* Li and Xiao, 2004 overlaps with the last appearance of *Sinosachites flabelliformis* He, 1980 and *Lapworthella rete* Yue, 1987 in the lower Yuanshan Formation (Li and Xiao 2004). The last occurrence of *L. rete* defines the upper boundary of the *S. flabelliformis-T. zhangwentangi* Assemblage Zone in South China (Steiner et al., 2007). Thus, co-occurrence of *Micrina*, *Lapworthella* and halkieriid sclerites (likely to be *Sinosachites*) in the *M. etheridgei* Zone can be correlated with the upper part of the *S. flabelliformis-T. zhangwentangi* Assemblage Zone in China.

Lapworthella rete and *Conotheca brevica* Qian, Xie and He, 2001 have been reported from the Marcory Formation, southern France, which Devaere et al., (2014a) correlates with the *S. flabelliformis-T. zhangwentangi* Assemblage Zone in China based on co-occurrence of the taxa in both localities. Hyoliths are abundant in the AJX-M section which includes taxa such as *Triplicatella disdoma* Conway Morris in Bengtson et al., 1990 (Skovsted et al., 2014b), and *Cupitheca holocyclata* Bengtson in Bengtson et al., 1990 (Skovsted et al., 2016), and probable conothecids. They co-occur with *Lapworthella* in the *M. etheridgei* Zone providing a temporal link with the Marcory Formation, southern France and the *S. flabelliformis-T. zhangwentangi* Assemblage Zone in China.

Some brachiopods that first appear in the *M. etheridgei* Zone also have a global distribution. *Eoobolus*, for example, is widely dispersed, but this genus is currently poorly defined and probably represents a "wastebasket" taxon that is very long ranging, which currently limits biostratigraphic application (Ushatinskaya, 2012). In addition, *Askepasma transversalis* Peng, Zhao, Qin, Yan and Ma, 2010 from the lower Cambrian Balang Formation, eastern Guizhou is the only occurrence of the genus outside Australia (Peng et al., 2010). However, in the Balang Formation, this taxon co-occurs with *Redlichia chinensis* Walcott, 1905. In Australia, *Redlichia* occurs in younger strata (Series 2, late Stage 4) (Laurie, 2006), and hence is unlikely to correlate with the zones described herein.

900 Furthermore, the illustrated specimens have a more prominent pedicle beak than either
901 *Askepasma toddense* or *A. saproconcha* and do not display the reticulate microornament
902 diagnostic of the genus, leaving identification and correlation of these specimens in doubt.

903 Bradoriid fauna have often been used to distinguish Cambrian biogeographic
904 provinces (Siveter and Williams, 1997; Melnikova et al., 1997; Williams and Siveter, 1998;
905 Hou et al., 2002; Williams et al., 2007; Topper et al., 2011b). Australian bradoriid
906 assemblages bear close taxonomic similarities (at the genus level) with those from South
907 China (Topper et al., 2007, 2011b; Betts et al., 2014), though genera in Australia are typically
908 correlated to older strata. For example, *Jiucunella* was thought to be endemic to China until
909 the recent description of *Jiucunella phaseloa* from the Arrowie Basin (Betts et al., 2014).
910 *Jiucunella phaseloa* is restricted to the *M. etheridgei* Zone in South Australia. In South
911 China, the morphologically similar *Jiucunella paulaula* is restricted to the slightly younger
912 *Eoredlichia-Wutingaspis* Zone in the Qiongzhusian Formation in Chengjiang County,
913 Yunnan (Hou & Bergström, 1991; Hou et al., 2002).

914 Similarly, *Jixinlingella* was only known from the lower Cambrian Shuijingtuo
915 Formation (*Eoredlichia-Wutingaspis* Zone), Shaanxi, central China (Lee 1975; Zhang 2007)
916 before *Jixinlingella daimonikoa* was described by Betts et al. (2014) from the *M. etheridgei*
917 Zone. In addition, *Neokunmingella* cf. *minuta* ranges from the *Eoredlichia-Wutingaspis* Zone
918 in the Qiongzhushi Formation to the *Palaeolenus* Zone in the Canglangpu Formation in
919 South China (Hou et al., 2002). *Neokunmingella shuensis* is also recorded from the
920 *Eoredlichia-Wutingaspis* Zone in Southern China (Zhang, 2007). In the Arrowie Basin,
921 *Neokunmingella moroensis* appears to represent an older occurrence, being restricted to the
922 *M. etheridgei* Zone in the MORO and MOG sections.

923

8. CONCLUSION

This new biostratigraphic scheme applies the widely adopted methodology of defining only lower boundaries based on first occurrences of diagnostic fossils in a stratigraphic section, which simplifies both the definitions and visual representation of the zones. Unrecognised time-breaks between zones (e.g. boundary between the *M. etheridgei* and *D. odyssei* zones) can confound accurate identification of biozone boundaries, frustrating correlation at regional (and global) scale. This is further supports the need for integrating multi-proxy datasets, particularly biostratigraphy and chemostratigraphy to calibrate and circumvent shortcomings of relative dating methods.

Definition of internationally acceptable boundaries for lower Cambrian chronostratigraphic subdivisions remains unresolved, especially the base of Stages 2, 3 and 4. Many previous biostratigraphic schemes for Australia have utilised Siberian stages (e.g. Kruse et al., 2009) or the depositional sequence sets of Gravestock and Cowley (1995). Resolving this issue ultimately hinges on the resolution of biostratigraphic ranges of shelly fauna through regional, basin-scale sequences.

Absence of trilobites below the Cambrian Series 2, Stage 3 *Abadiella huoi* trilobite Zone means that other faunal groups must be employed to fill this biostratigraphic gap in East Gondwana. Schemes based on acritarchs (Zang in Gravestock et al., 2001; Zang 2001; Zang et al., 2007), archaeocyaths (Gravestock, 1984; Zhuravlev and Gravestock, 1994) and ichnofossils (Droser et al., 1999) have been used with varying success. Biozones based on shelly fossils have great potential to fill the pre-trilobitic gap in Australia and contribute meaningfully to lower Cambrian regional and global correlation.

Measured sections have yielded abundant shelly fossils from the Wilkawillina, Wirrapowie and Ajax limestones, the biostratigraphic ranges of which are predictable and

948 repeatable across the basin. This has resulted in the establishment of three new biozones (in
949 ascending order): the *Kulparina rostrata* Zone, *Micrina etheridgei* Zone, and the *Dailyatia*
950 *odyssei* Zone. The *D. odyssei* Zone is associated predominantly with the Mernmerna
951 Formation (and equivalent strata) and will be documented in greater detail in a subsequent
952 paper. These zones intersect the fossiliferous part of the Hawker Group in the Arrowie Basin,
953 South Australia and allow robust correlation both within the basin and with coeval
954 depocentres such as the Stansbury, Amadeus, Georgina and Officer basins. The endemic
955 nature of many of the taxa utilised in this scheme, restrict global correlation. However, faunal
956 correlation with China is enabled through occurrences of several cosmopolitan shelly fossil
957 genera (and species), indicating that the *K. rostrata* and *M. etheridgei* zones correlate with
958 the Meishucunian *S. flabelliformis-T. zhangwengtangi* Assemblage Zone in China. Therefore,
959 the Australian zones range from the upper Terreneuvian Series, Stage 2 to Series 2, Stage 3.

960

961 Acknowledgements

962 Financial support for this project was provided by ARC Discovery Project
963 (DP120104251) to GAB and JRP, and Macquarie University HDR funds to MJB. The
964 authors would like to thank the following for their assistance in the field and/or with sample
965 processing in the lab: David Mathieson, Bo Jonak, Mitch Smith, Briony Mamo, Sarah
966 Collison, Brett Pyemont, James Valentine, Hayley Bell and David Keith. Thanks to Debra
967 Birch and Nicole Vella at the Microscopy Unit at Macquarie University for assistance with
968 imaging, and to Dean Oliver Graphics for drafting of Figure 1. The authors are grateful to
969 property owners Julie and Bill Reschke (Mulga View Station), Ian and Di Fargher
970 (Angorichina), and Graham and Laura Ragless (Beltana) for accommodation and field access.
971 We are also grateful to the Adnyamathana People of Nepabunna for allowing the field teams

to conduct fieldwork on their land. The manuscript benefitted from constructive reviews from one anonymous reviewer.

References

Alexander, E., Gravestock, D., 1990. Sedimentary facies in the Sellick Hill Formation, Fleurieu Peninsula, South Australia. Geological Society of Australia, Special Publication 16, 269-289.

Álvaro, J.J., Benziane, F., Thomas, R., Walsh, G.J., Yazidi, A., 2014. Neoproterozoic–Cambrian stratigraphic framework of the Anti-Atlas and Ouzellagh promontory (High Atlas), Morocco. Journal of African Earth Sciences 98, 19-33.

Babcock, L.E., Peng, S.-C., Brett, C.E., Zhu, M.-Y., Ahlberg, P., Bevis, M. and Robison, R.A. 2015. Global climate, sea level cycles, and biotic events in the Cambrian Period. Palaeoworld 24, 5-15.

Balthasar, U., 2004. Shell structure, ontogeny and affinities of the Lower Cambrian bivalved problematic fossil *Mickwitzia muralensis* Walcott, 1913. Lethaia 37, 381-400.

Balthasar, U., 2009. The brachiopod *Eoobolus* from the Early Cambrian Mural Formation (Canadian Rocky Mountains). Paläontologische Zeitschrift 83, 407-418.

Barrande, J. 1881. Systême Silurien du centre de la Bohême, Vol. 6, Acéphalés, Paris and Prague, 342 p.

Bedford, R. and Bedford, J., 1939. Development and Classification of the archeos (pleospongia) from the Lower Cambrian of South Australia. Kyancutta Museum Memoirs 6, 67-82.

Bengtson, S. 1970. The Lower Cambrian fossil Tommotia. Lethaia 3, 363-392.

995 Bengtson, S., Morris, S.C. and Cooper, B.J., Jell, P.A. and Runnegar, B.N. 1990. Early
996 Cambrian fossils from south Australia. Memoir of the Association of Australasian
997 Palaeontologists 9, 1-364.
998 Betts, M.J. 2012. Small Shelly Fossils and archaeocyath bioherms from lower Cambrian
999 Hawker Group carbonates at Moro Gorge, central Flinders Ranges. Unpublished
1000 Honours thesis, Macquarie University.
1001 Betts, M.J., Brock, G.A. and Paterson, J.R. 2016. Butterflies of the Cambrian benthos? Shield
1002 position in bradoriid arthropods. Lethaia. DOI: 10.1111/let.12160.
1003 Betts, M.J., Brock, G.A., Paterson, J.R., Jago, J.B. and Andrew, A.S. 2015. Integrated Shelly
1004 Fossil Biostratigraphy and Carbon and Oxygen Chemostratigraphy: Applying a Multi-
1005 proxy Toolkit to Correlating the Lower Cambrian of South Australia. AAPG/SEG
1006 International Conference and Exhibition, Melbourne, Australia. Abstracts with
1007 Programs.
1008 Betts, M.J., Topper, T.P., Skovsted, C.B., Brock, G.A. and Paterson, J.R. 2012. A bounty of
1009 bradoriids – biodiversity, biogeography and biostratigraphy of richly diverse lower
1010 Cambrian assemblages from South Australia. 34th International Geological Congress,
1011 Brisbane. Abstracts with Programs.
1012 Betts, M.J., Topper, T.P., Valentine, J.L., Skovsted, C.B., Paterson, J.R. and Brock, G.A.
1013 2014. A new early Cambrian bradoriid (Arthropoda) assemblage from the northern
1014 Flinders Ranges, South Australia. Gondwana Research 25, 420-437.
1015 Bischoff, G.C.O., 1976. *Dailyatia*, a new genus of the Tommotiidae from Cambrian strata of
1016 SE Australia (Crustacea, Cirripedia). Senkenbergiana Lethaea 57, 1–33.
1017 Brasier, M.D. 1986: The succession of small shelly fossils (especially conoidal microfossils)
1018 from English Precambrian–Cambrian boundary beds. Geological Magazine 123, 237-
1019 256.

1020 Brock, G.A., Alexander, E.M., Paterson, J.R., Jago, J.B. and Gatehouse, C.G. 2006. Mt. Scott
1021 Range and Ajax Mine. *In:* Jago, J.B. and Zang, W.-L. (eds.), XI International
1022 Conference of the Cambrian Stage Subdivision Working Group Field Guide. South
1023 Australia: International Subcommission on Cambrian Stratigraphy.
1024 Brock, G.A., Cooper, B.J., 1993. Shelly fossils from the early Cambrian (Toyonian)
1025 Wirrealpa, Aroona Creek, and Ramsay Limestones of South Australia. Journal of
1026 Paleontology 67, 758-787.
1027 Brock, G.A., Engelbretsen, M.J., Jago, J.B., Kruse, P.D., Laurie, J.R., Shergold, J.H., Shi,
1028 G.R. and Sorauf, J.E. 2000. Palaeobiogeographic affinities of Australian Cambrian
1029 faunas. Memoir of the Association of Australasian Palaeontologists 23, 1-62.
1030 Brock, G.A., Holmer, L.E., Skovsted, C.B., Stemmerik, L. and Myrow, P. 2012. Hot fossils
1031 in a cold land: early Cambrian stem group bilaterians from Antarctica. *34th*
1032 *International Geological Congress, Brisbane*. Abstracts with Programs.
1033 Brock, G.A. and Paterson, J.R. 2004. A new species of *Tannuella* (Helcionellida, Mollusca)
1034 from the Early Cambrian of South Australia. Memoir of the Association of
1035 Australasian Palaeontologists 30, 133-143.
1036 Brougham, T. 2009. The oldest skeletonised fossil assemblages in Australia: The fauna of the
1037 lower Cambrian Normanville Group, Fleurieu Peninsula, South Australia.
1038 Unpublished Honours thesis, Macquarie University.
1039 Chang, W., 1966. On the classification of Redlichiacea, with description of new families and
1040 new genera. Acta Palaeontologica Sinica 14, 135-184.
1041 Clarke, J.D.A. 1986a. Subdivision of the lower part of the Wilkawillina Limestone, eastern
1042 Flinders Ranges. Quarterly Geological Notes - Geological Survey of South Australia
1043 97, 12-17.

1044 Clarke, J.D.A. 1986b. Stratigraphy and sedimentology of the upper part of the Wilkawillina
1045 Limestone, Wilkawillina Gorge, Flinders Ranges. Quarterly Geological Notes -
1046 Geological Survey of South Australia 100, 2-7.
1047 Clarke, J.D.A. 1986c. Subdivision of the Early Cambrian Parara Limestone at Wilkawillina
1048 Gorge, Flinders Ranges. Quarterly Geological Notes - Geological Survey of South
1049 Australia 99, 1-7.
1050 Clarke, J.D.A. 1990a. An early Cambrian carbonate platform near Wilkawillina Gorge, South
1051 Australia. Australian Journal of Earth Sciences 37, 471-483.
1052 Clarke, J.D.A. 1990b. Slope facies deposition and diagenesis of the early Cambrian Parara
1053 Limestone, Wilkawillina Gorge, South Australia. The evolution of a late
1054 Precambrian-early Palaeozoic rift complex: the Adelaide Geosyncline, 230-246.
1055 Clausen, S. and Álvaro, J.J. 2006. Skeletonized microfossils from the Lower-Middle
1056 Cambrian transition of the Cantabrian Mountains, northern Spain. Acta
1057 Palaeontologica Polonica 51, 223-238.
1058 Cobbold, E.S., 1921. The Cambrian horizons of Comley (Shropshire) and their Brachiopoda,
1059 Pteropoda, Gasteropoda and etc. The Quarterly Journal of the Geological Society of
1060 London 76, 325–386.
1061 Cooper, B.J. and Jago, J.B., 2007. History of Cambrian investigations in South Australia with
1062 particular reference to the biostratigraphy. Memoirs of the Australasian Association of
1063 Palaeontologists 33, 1-27.
1064 Daily, B. 1956. The Cambrian in South Australia. 91-147 in Rodgers, J. (ed), El Sistema
1065 Cambrico, su paleogeografia y el problema de su base, Report 20th International
1066 Geological Congress, Mexico 2.
1067 Daily, B. 1972. The base of the Cambrian and the first Cambrian faunas. 13-41 in Jones, J. B.
1068 and McGowran, B. (eds.), Centre for Precambrian Research, Special Paper No. 1,

1069 Stratigraphic Problems of the Later Precambrian and Early Cambrian. South
1070 Australia: University of Adelaide.
1071 Daily, B. 1976. New data on the base of the Cambrian in South Australia. Izvestiya Akademii
1072 Nauk. SSSR, Seriya Geologicheskaya 3, 45-52.
1073 Dalgarno, C., 1964. Lower Cambrian stratigraphy of the Flinders ranges. Transactions of the
1074 Royal Society of South Australia 88, 129-144.
1075 Demidenko, Y.E. 1999. Skeletnye problematichnye ostatki iz nizhuego kembriya Yuzhnoy
1076 Avstralii (Skeletal problematic remains from the lower Cambrian of South Australia).
1077 Avtoreferat dissertatsii kandidata geologo-nimeralogicheskikh nauk, Moscow,
1078 Moscow State University (unpublished, in Russian).
1079 Demidenko, Y.E. and Parkhaev, P.Y. 2014. On the problem of recognition of the lower
1080 Tommotian boundary using SSF. In: Zhan, R. and Huang, B. (eds.) IGCP Project 591,
1081 Field Workshop. Nanjing University Press.
1082 Devaere, L., Clausen, S., Steiner, M., Álvaro, J.J. and Vachard, D. 2013. Chronostratigraphic
1083 and palaeogeographic significance of an early Cambrian microfauna from the
1084 Heraultia Limestone, northern Montagne Noire, France. Palaeontologia Electronica
1085 16, 1-91.
1086 Devaere, L., Clausen, S., Monceret, E., Tormo, N., Cohen, H., Vachard, D., 2014a.
1087 Lapworthellids and other skeletonised microfossils from the Cambrian Stage 3 of the
1088 northern Montagne Noire, southern France. Annales de Paleontologie 100, 175-191.
1089 Devaere, L., Clausen, S., Monceret, E., Vizcaïno, D., Vachard, D., Genge, M.C., 2014b. The
1090 tommotiid *Kelanella* and associated fauna from the early Cambrian of southern
1091 Montagne Noire (France): implications for camenellan phylogeny. Palaeontology 57,
1092 979-1002.

1093 Droser, M.L., Gehling, J.G., Jensen, S., 1999. When the worm turned: concordance of Early
1094 Cambrian ichnofabric and trace-fossil record in siliciclastic rocks of South Australia.
1095 *Geology* 27, 625-628.
1096 Dunster, J.N., Kruse, P.D., Duffet, M.L., Ambrose, G.J., 2007. Geology and Resource
1097 Potential of the southern Georgina Basin. Northern Territory Geological Survey,
1098 Digital Information Package (DIP007), pp. 232.
1099 Emmons, E. 1844. The Taconic System: Based on Observations in New-York,
1100 Massachusetts, Maine, Vermont and Rhode-Island. Albany, New York, 653p.
1101 English, A.M., and Babcock, L.E., 2010, Census of the Indian Springs Lagerstätte, Poleta
1102 Formation (Cambrian), western Nevada, USA. Palaeogeography, Palaeoclimatology,
1103 Palaeoecology 295, 236–244.
1104 Etheridge, R. 1890. On some Australian species of the family Archaeocyathinae.
1105 Transactions of the Royal Society of South Australia 13, 10-22.
1106 Evans, K.R. 1992. *Marocella*; Antarctic specimens of an enigmatic Cambrian animal. Journal
1107 of Paleontology 66, 558-562.
1108 Evans, K.R. and Rowell, A.J. 1990. Small shelly fossils from Antarctica: an early Cambrian
1109 faunal connection with Australia. Journal of Paleontology 64, 692-700.
1110 Gedik, I. 1977. Conodont stratigraphy in the Middle Taurus. Bulletin of the Geological
1111 Society of Turkey 20, 35–48 (in Turkish with English abstract).
1112 Geyer, G. 2001. Correlation in the Cambrian: Puzzling facts or wrong concepts? Palaeoworld
1113 13, 87-98.
1114 Geyer, G. 1986. Mittelkambrische mollusken aus Marokko und Spanien. Senckenbergiana
1115 Lethaea 67, 55-118.
1116 Geyer, G. and Shergold, J.H. 2000. The quest for internationally recognized divisions of
1117 Cambrian time. Episodes 23, 188-195.

1118 Grabau, A. 1900. Palaeontology of the Cambrian terranes of the Boston basin. Occasional
1119 Papers of the Boston Natural History Society 4, 601-694.
1120 Gravestock, D.I. 1984. Archaeocyatha from lower parts of the Lower Cambrian carbonate
1121 sequence in South Australia. Memoir of the Association of Australasian
1122 Palaeontologists 2, 139.
1123 Gravestock, D.I., Morton, J. and Zang, W. 1997. Biostratigraphy and correlation. In: Morton,
1124 J. and Drexel, J. (eds.), Petroleum Geology of South Australia 3, 87-97.
1125 Gravestock, D.I. and Shergold, J.H. 2001. Australian Early and Middle Cambrian sequence
1126 biostratigraphy with implications for species diversity and correlation, United States
1127 (USA), Columbia University Press, New York, United States (USA).
1128 Gravestock, D.I. 1988. Early Cambrian carbonates in the Flinders Ranges. In: Jenkins, R.J.F.
1129 and Gravestock, D.I. (eds.), Proterozoic Ediacara fauna and Cambrian Archaeocyatha
1130 of the Flinders Ranges, South Australia. 5th International Symposium on fossil
1131 Cnidaria. Brisbane: Excursion A2.
1132 Gravestock, D.I. 1995. Early and Middle Palaeozoic. In: Drexel, J. F., Preiss, W.V. (ed.), The
1133 Geology of South Australia, vol. 2, The Phanerozoic. South Australia: Geological
1134 Survey.
1135 Gravestock, D.I., Alexander, E.M., Demidenko, Y.E., Esakova, N.B., Holmer, L.E., Jago,
1136 J.B., Lin, T.-R., Melnikova, N., Parkhaev, P.Y., Rozanov, A.Y., Ushatinskaya, G.T.,
1137 Sang, W.-L., Zhegallo, E. A. and Zhuravlev, A.Y. 2001. The Cambrian
1138 biostratigraphy of the Stansbury Basin, South Australia. Transactions of the
1139 Palaeontological Institute of the Russian Academy of Sciences 282, 1-341.
1140 Gravestock, D.I. and Cowley, W.M. 1995. Arrowie Basin. In: Drexel, J.F., Preiss, W.V. (ed.),
1141 The geology of South Australia. Volume 2 - The Phanerozoic. Mines and Energy
1142 South Australia Bulletin Vol. 54.

1143 Gravestock, D.I., Hibburt, J.E. 1991. Sequence stratigraphy of the eastern Officer and
1144 Arrowie Basins: a framework for Cambrian oil search. APEA Journal, 31, 177-190.
1145 Guo, J., Li, Y. and Li, G. 2014. Small shelly fossils from the early Cambrian Yanjiahe
1146 Formation, Yichang, Hubei, China. Gondwana Research 25, 999-1007.
1147 Haslett, P. 1975. The Woodendinna Dolomite and Wirrapowie Limestone; two new lower
1148 Cambrian formations, Flinders Ranges, South Australia. Transactions of the Royal
1149 Society of South Australia 99, 211-219.
1150 He, T.-G. 1980. Arthropoda. 182–197. In Yin, J.-C., Ding, L.- F., He, T.-G., Li , S.-L. and
1151 Shen, L.-J. (eds). The palaeontology and sedimentary environment of the Sinian
1152 system in Emei-Ganluo Area, Sichuan. Sichuan Peoples Publishing House, Chengdu,
1153 231 pp, (In Chinese, with English Summary).
1154 Hollingsworth, J.S., and Babcock, L.E., 2011, Base of Dyeran Stage (Cambrian Stage 4) in
1155 the middle member of the Poleta Formation, Indian Springs Canyon, Montezuma
1156 Range, Nevada. Museum of Northern Arizona Bulletin 67, 256–262.
1157 Hou, X.-G., Bergstrom, J., 1991. The arthropods of the Lower Cambrian Chengjiang fauna,
1158 with relationships and evolutionary significance. In: Simonetta, A.M., Conway
1159 Morris, S. (eds.), The Early Evolution of Metazoa and the Significance of Problematic
1160 Taxa. Cambridge University Press, Cambridge, pp. 179–187.
1161 Hou, X.-G., Siveter, D.J., Williams, M., Xiang-Hong, F., 2002. A monograph of the
1162 Bradoriid arthropods from the Lower Cambrian of SW China. Transactions of the
1163 Royal Society of Edinburgh 93, 347-409.
1164 Howchin, W., 1922. A geological traverse of the Flinders Ranges from the Parachilna Gorge
1165 to the Lake Frome Plains. Transactions of the Royal Society of South Australia 46,
1166 46-82.

1167 Howchin, W. 1925. The geographical distribution of fossiliferous rocks of Cambrian age in
1168 South Australia with geological notes and references. Transactions of the Royal
1169 Society of South Australia 49, 1-26.
1170 Huo S.-C. 1956. Brief notes on Lower Cambrian Archaeostraca from Shensi and Yunnan.
1171 Acta Palaeontologia Sinica 4, 425-445.
1172 Hupé, P.R., 1953. Contribution à l'étude du Cambrien inférieur et du Précambrien III de
1173 l'Anti-Atlas Marocain. Direction de la Production Indrustrielle et des Mines, Division
1174 des Mines et de la Géologie, Servide Géolgique, Notes et Mémoires 103, 1-402.
1175 Hupé, P., 1960. Sur le Cambrien inférieur du Maroc. Report 21st International Geological
1176 Congress 8, 75-85.
1177 Jacquet, S.M., Brock, G.A., Paterson, J.R., 2014. New data on *Oikozetetes* (Mollusca,
1178 Halkieriidae) from the lower Cambrian of South Australia. Journal of Paleontology
1179 88, 1072-1084.
1180 Jacquet, S.M., Brock, G.A., 2015. Lower Cambrian helcionelloid macromolluscs from South
1181 Australia. Gondwana Research. DOI:10.1016/j.gr.2015.06.012.
1182 Jago, J.B., Daily, B.D., Von Der Borch, C.C., Cernovskis, A., Saunders, N., 1984. First
1183 reported trilobites from the Lower Cambrian Normanville Group, Fleurieu Peninsula,
1184 South Australia. Transactions of the Royal Society of South Australia 108, 207-211.
1185 Jago, J.B., Gehling, J.G., Paterson, J.R., Brock, G.A. and Zang, W.-L. 2012. Cambrian
1186 stratigraphy and biostratigraphy of the Flinders Ranges and the north coast of
1187 Kangaroo Island, South Australia. Episodes 35, 247.
1188 Jago, J.B., Lin, T.-R. and Dunster, J.N. 2002a. A new species of the trilobite *Abadiella* from
1189 the Lower Cambrian of the eastern Officer Basin, South Australia. Acta
1190 Palaeontologica Sinica 41, 428-433.

1191 Jago, J.B., Sun, X. and Zang, W.-L. 2002b. Correlation within early Palaeozoic basins of
1192 eastern South Australia. Primary Industries and Resources, South Australia Report
1193 Book 2002/033, 1-22.
1194 Jago, J.B., Zang, W.-L., Sun, X., Brock, G.A., Paterson, J.R. and Skovsted, C.B. 2006. A
1195 review of the Cambrian biostratigraphy of South Australia. Palaeoworld 15, 406-423.
1196 James, N.P. and Gravestock, D.I. 1990. Lower Cambrian shelf and shelf margin buildups,
1197 Flinders Ranges, South Australia. Sedimentology 37, 455-480.
1198 Jell, P.A. 1980. Earliest known bivalve on Earth—A new Early Cambrian genus from South
1199 Australia. Alcheringa 4, 233–239.
1200 Jell, P.A. 1981. *Thambetolepis delicata* gen. et. sp. nov., an enigmatic fossil from the early
1201 Cambrian of South Australia. Alcheringa 5, 85-93.
1202 Jensen, S. 1993. Trace fossils, body fossils, and Problematica from the Lower Cambrian
1203 Mickwitzia Sandstone, South-Central Sweden [Ph.D. dissertation]. Uppsala, Uppsala
1204 University, Sweden, 171 p.
1205 Khomentovsky, V.V. and Karlova, G.A. 1993. Biostratigraphy of the Vendian-Cambrian
1206 beds and the lower Cambrian boundary in Siberia. Geological Magazine 130, 29-45.
1207 Knoll, A.H., Kaufman, A.J., Semikhatov, M.A. and Grotzinger, J.P. 1996. Sizing up the sub-
1208 Tommotian unconformity in Siberia. Geology 23, 1139-1143.
1209 Koneva, S.P. 1979. Stenotekoidy i bezzamkovye brakhiopody nizhnego i nizov srednego
1210 kembriia Tsentralnogo Kazakhstana. [Stenotecoids and inarticulate brachiopods from
1211 the Lower and lower Middle Cambrian of Central Kazakhstan.] Akademiya Nauk
1212 Kazakhstkoj SSR, Ordena trudovogo krasnogo znameni, Institut geologicheskikh
1213 nauk im. K. I. Satpaeva, Nauka, Alma-ata, 123 pp.

1214 Kouchinsky, A., Bengtson, S., Runnegar, B., Skovsted, C., Steiner, M. and Vendrasco, M.
1215 2012. Chronology of Early Cambrian biomineralization. Geological Magazine 149,
1216 221-251.
1217 Kruse, P.D., Jago, J.B. and Laurie, J.R. 2009. Recent developments in Australian Cambrian
1218 biostratigraphy. Journal of Stratigraphy 33, 35-47.
1219 Kruse, P.D. and West, P.W. 1980. Archaeocyatha of the Amadeus and Georgina basins.
1220 BMR journal of Australian Geology and Geophysics 5, 165-181.
1221 Landing, E. 1988: Lower Cambrian of eastern Massachusetts: stratigraphy and small shelly
1222 fossils. Journal of Paleontology 661-695.
1223 Landing, E. 1994. Precambrian-Cambrian boundary global stratotype ratified and a new
1224 perspective of Cambrian time. Geology 22, 179-182.
1225 Landing, E. and Geyer, G. 2012. Misplaced faith–limitations of the first appearance datum
1226 (FAD) in chronostratigraphy and proposal of more robust Lower Cambrian
1227 correlation standards. Journal of Guizhou University (Natural Science) *29*
1228 (supplement) 170-171.
1229 Landing, E., Geyer, G., Brasier, M.D. and Bowring, S.A. 2013. Cambrian Evolutionary
1230 Radiation: Context, correlation, and chronostratigraphy-Overcoming deficiencies of
1231 the first appearance datum (FAD) concept. Earth-Science Reviews 123, 133-172.
1232 Landing, E., Nowlan, G.S., and Fletcher, T.P. 1980. A microfauna associated with Early
1233 Cambrian trilobites of the Callavia Zone, norther Antigonish Highlands, Nova Scotia.
1234 Canadian Journal of Earth Sciences 17, 400-418.
1235 Larsson, C.M., Skovsted, C.B., Brock, G.A., Balthasar, U., Topper, T.P. and Holmer, L.E.
1236 2014. *Paterimitra pyramidalis* from South Australia: scleritome, shell structure and
1237 evolution of a lower Cambrian stem group brachiopod. Palaeontology 57, 417-446.

1238 Laurie, J.R. and Shergold, J.H. 1985. Phosphatic organisms and the correlation of Early
1239 Cambrian carbonate formations in central Australia. BMR Journal of Australian
1240 Geology and Geophysics 9, 83-89.
1241 Laurie, J.R. 1986. Phosphatic fauna of the Early Cambrian Todd River Dolomite, Amadeus
1242 Basin, central Australia. Alcheringa 10, 431-454.
1243 Laurie, J.R., 2006. Early Middle Cambrian trilobites from Pacific Oil and Gas Baldwin 1
1244 well, southern Georgina Basin, Northern Territory. Memoir of the Association of
1245 Australasian Palaeontologists 32, 127.
1246 Lee, Y.-W., 1975. On the Cambrian Ostracoda with new material from Sichuan, Yunnan and
1247 southern Shaanxi, China. Professional Papers on Stratigraphy and Palaeontology, 2.
1248 Geological Publishing House, Beijing, pp. 37–72.
1249 Li, G., and Holmer, L.E. 2004. Early Cambrian lingulate brachiopods from the Shaanxi
1250 Province, China. *GFF* 126, 193-211.
1251 Li, G. and Xiao, S. 2004: *Tannuolina* and *Micrina* (Tannuolinidae) from the Lower Cambrian
1252 of eastern Yunnan, south China, and their scleritome reconstruction. Journal of
1253 Paleontology 78, 900-913.
1254 Lu, Y.-H., Chang, W.-T., Qian, Y.-Y., Zhu, Z.-L. and Lin, H.-L. 1974. Cambrian trilobites,
1255 82–107. In, Nanjing Institute of Geology and Palaeontology. Handbook of
1256 stratigraphy and palaeontology in southwestern China. 454 pp. Science Press, Beijing.
1257 (in Chinese with English summary).
1258 Lu, Y.-H., and Dong, N.-T. 1952. Revision of the Cambrian type sections of Shantung. Acta
1259 Geologica Sinica 32, 164–201.
1260 Magaritz, M., Kirschvink, J.L., Latham, A.J., Zhuravlev, A.Y., Rozanov, A.Y., 1991.
1261 Precambrian/Cambrian boundary problem: Carbon isotope correlations for Vendian
1262 and Tommotian time between Siberia and Morocco. Geology 19, 847-850.

1263 Maloof, A.C., Ramezani, J., Bowring, S.A., Fike, D.A., Porter, S.M. and Mazouad, M. 2010.
1264 Constraints on Early Cambrian carbon cycling from the duration of the Nemakit-
1265 Daldynian-Tommotian boundary $\delta^{13}C$ shift, Morocco. Geology 38, 623-626.
1266 Mángano, M.G., Buatois, L.A., 2014. Decoupling of body-plan diversification and ecological
1267 structuring during the Ediacaran–Cambrian transition: evolutionary and geobiological
1268 feedbacks. Proceedings of the Royal Society B 281: 20140038.
1269 Matthew, G.F. 1895. The *Protolenus* fauna. Science 1, 452–453.
1270 Matthew, G.F. 1902. Notes on Cambrian faunas. Royal Society of Canada, Transactions Ser.
1271 2, Sect. A, 93-112.
1272 Mawson, D. 1937. The most northerly occurrence of fossiliferous Cambrian strata yet
1273 recorded in South Australia. Transactions of the Royal Society of South Australia 61,
1274 181-186.
1275 Mawson, D. 1939. The Cambrian sequence in the Wirrealpa Basin. Transactions of the Royal
1276 Society of South Australia 63, 331-347.
1277 Mawson, D. 1938. Cambrian and Sub-Cambrian Formations at Parachilna Gorge.
1278 Transactions of the Royal Society of South Australia, 62 255-262.
1279 Melnikova, L.M., 1998. Revision of some Cambrian bradoriids (Crustacea) from the Siberian
1280 Platform. Paleontological Journal 32, 357-361.
1281 Melnikova, L.M., Siveter, D.J., Williams, M., 1997. Cambrian Bradoriida and
1282 Phosphatocopida (Arthropoda) of the former Soviet Union. Journal of
1283 Micropalaeontology 16, 179-191.
1284 Missarzhevsky, V.V. 1969. Paleontologicheskoj chast. In Tommotskij yarus i problema
1285 nizhnej granitsky kembriya. Edited by A. Y. Rozanov. Trudy Geologiy Institut
1286 Akademia Nauk SSSR 206, pp. 94-194.

1287 Missarzhevsky, V.V. 1977. Konodonty (?) I fosfatnye problematiki kenbryia Mongolii i
1288 Sibiri. In, Bespozvonochnye Paleozoya Mongolii, Trudy Svomestaya Sovetsko-
1289 Mongolskaya Paleontologicheskaya Ekspeditsiya, 10-19. (In Russian).
1290 Missarzhevsky, V.V., Mambetov, A., 1981. Stratigrafiya i fauna pogranichnykh sloev
1291 kembriya i dokembriya Malogo Karatau. Trudy Ordena Trudovogo Krasnogo
1292 Znameni Geologicheskiy Institut, Akademiya Nauk SSSR 326, 92.
1293 Murdock, D.J., Donoghue, P. C., Bengtson, S. and Marone, F. 2012. Ontogeny and
1294 microstructure of the enigmatic Cambrian tommotiid *Sunnaginia* Missarzhevsky,
1295 1969. Palaeontology 55, 661-676.
1296 Neltner, L. and Poctey, N. 1950. Quelques faunes ge´orgiennes du Maroc. Notes et
1297 Me´moires du Service Ge´ologiques du Maroc 74, 53– 83.
1298 Palmer, A.R. and Rowell, A.J. 1995. Early Cambrian trilobites from the Shackleton
1299 Limestone of the Central Transantarctic Mountains. Paleontological Society Memoir
1300 45, 1-28.
1301 Parkhaev, P.Y. 2001. The functional morphology of the Cambrian univalved mollusks-
1302 helcionellids. Paleontological Journal 35, 20-26.
1303 Parkhaev, P.Y. 2000. The Functional Morphology of the Cambrian Univalved Mollusks-
1304 Helcionellids. 1. *Paleontological Journal* 34, 392-399.
1305 Parkhaev, P.Y. 2014. On the stratigraphy of *Aldanella attleborensis* - potential index-species
1306 for defining the base of Cambrian Stage 2. In Zhan, R. and Huang, B. (eds.), IGCP
1307 Project 591, Field Workshop. Nanjing University Press.
1308 Paterson, J.R. and Brock, G.A. 2007. Early Cambrian trilobites from Angorichina, Flinders
1309 Ranges, South Australia, with a new assemblage from the Pararaia bunyerooensis
1310 Zone. Journal of Paleontology 81, 116-142.

1311 Paterson, J.R., Skovsted, C.B., Brock, G.A. and Jago, J.B. 2007. An Early Cambrian faunule
1312 from the Koolywurtie Limestone Member (Parara Limestone), Yorke Peninsula,
1313 South Australia and its biostratigraphic significance. Memoir of the Association of
1314 Australasian Palaeontologists 34, 131-146.
1315 Peng, S.-C, Babcock, L.E. and Cooper, R.A. 2012. The Cambrian Period. *The geologic time*
1316 *scale*, 2, 437-488.
1317 Peng, J., Zhao, Y.-L., Qin, Q., Yan, X., Ma, H.-T., 2010. New material of brachiopods from
1318 the Qiandonian (Lower Cambrian) Balang Formation, eastern Guizhou, South China.
1319 Acta Palaeontologica Sinica 49, 372-379.
1320 Popov, L.E., Holmer, L.E., Hughes, N.C., Ghobadi Pour, M. and Myrow, P.M. 2015.
1321 Himalayan Cambrian brachiopods. Papers in Palaeontology 1, 345-399.
1322 Poulsen, C., 1932. The Lower Cambrian faunas of East Greenland. Meddelelser om Grønland
1323 87, 1-66.
1324 Qian, Y., Zhang, S., 1983. Small shelly fossils from the Xihaoping Member of the Tongying
1325 Formation in Fangxian County of Hubei Province and their stratigraphical
1326 significance. Acta Palaeontologica Sinica 22, 93-99.
1327 Remane, J., Bassett, M.G., Cowie, J.W., Gohrbandt, K.H., Lane, H.R., Michelsen, O. and
1328 Wang, N. 1996. Revised guidelines for the establishment of global
1329 chronostratigraphic standards by the International Commission on Stratigraphy (ICS).
1330 Episodes, 19, 77-81.
1331 Rong, J.Y., 1974: Cambrian Brachiopods. In, Nanjing Institute of Geology and Paleontology,
1332 Academia Sinica, Handbook of Palaeontology and Stratigraphy of Southwest China,
1333 113–114. Science Press, Beijing.
1334 Rowell, A.J., Evans, K.R. and Rees, M.N. 1988: Fauna of the Shackleton Limestone.
1335 Antarctic Journal of the United States 23, 13-14.

1336 Rozanov, A.Y. 1995. Precambrian-Cambrian boundary of global stratotype ratified and a new
1337 perspective of Cambrian time; discussion and reply. Geology 23, 285-286.
1338 Rozanov, A.Y., Demidenko, V.V., Parkhaev, Y.Y., Skorlotova, G.A., Khomentovsky, A.I.,
1339 Karlova, V.A., Luchinina, T.V., Korovnikov, Y.E., Shabanov, P.Y., Pegel, I.V.,
1340 Varlamov, N.A., 2008. To the problem of stage subdivision of the Lower Cambrian.
1341 Stratigraphy and Geological Correlation 16, 1-19.
1342 Rozanov, A.Y., and Missarzhevsky, V.V. 1966. Biostratigraphy and Fauna of the Lower
1343 Horizons of the Cambrian. Proceedings of the Geological Institute of the Academy of
1344 Sciences of the USSR, Nauka, Moscow, 148.
1345 Rozanov, A. Y., Sokolov, B.S. (eds.) 1984. Yarusnoe raschlenie nizhnego kembriya,
1346 stratigrafiya. [Lower Cambrian Stage Subdivision, Stratigraphy], Nauka, Moscow (in
1347 Russian).
1348 Schmidt, F. 1888. Über eine neuentdeckte untercambrische Fauna in Estland. Académie
1349 Impériale des Sciences, St Petersbourg, Mémoires (series 7) 36, 1–27.
1350 Sdzuy, K., 1978. The Precambrian–Cambrian boundary beds in Morocco (preliminary
1351 report). Geological Magazine 115, 83-94.
1352 Sdzuy, K., 1981. Der Beginn des Phanerozoikums-Paläobiologische und stratigraphische
1353 Probleme. Natur und Museum 111, 390-399.
1354 Segnit, R.W. 1939. The Pre-Cambrian-Cambrian Succession: The General and Economic
1355 Geology of These Systems, in Portions of South Australia, Department of Mines,
1356 Geological Survey of South Australia, Bulletin 18, 191 pp.
1357 Shaler, N.S., Foerste, A.F., 1888. Preliminary description of North Attleboro fossils. Harvard
1358 Museum of Comparative Zoology Bulletin 16, 27–41.
1359 Shergold, J.H. 1996. Cambrian (Chart 1). In: Young, G. C., Laurie, J.R. (eds.) An Australian
1360 Phanerozoic Timescale. Melbourne: Oxford University Press.

1361 Siveter, D.J., Williams, M., 1997. Cambrian bradoriid and phosphatocopid arthropods of
1362 North America. Special Papers in Palaeontology 57, 1-69.
1363 Skovsted, C.B., Balthasar, U., Brock, G.A. and Paterson, J.R. 2009b. The tommotiid
1364 *Camenella reticulosa* from the early Cambrian of South Australia: Morphology,
1365 scleritome reconstruction, and phylogeny. Acta Palaeontologica Polonica 54, 525-
1366 540.
1367 Skovsted, C.B., Betts, M.J., Topper, T.P. and Brock, G.A. 2015a. The early Cambrian
1368 Tommotiid genus *Dailyatia* from South Australia. Memoir of the Association of
1369 Australasian Palaeontologists 48, pp. 117.
1370 Skovsted, C.B., Brock, G.A., Holmer, L.E. and Paterson, J.P. 2009a. First report of the early
1371 Cambrian stem group brachiopod *Mickwitzia* from East Gondwana. Gondwana
1372 Research 16, 145-150.
1373 Skovsted, C.B., Brock, G.A., Lindström, A., Peel, J.S., Paterson, J. R. and Fuller, M.K. 2007.
1374 Early Cambrian record of failed durophagy and shell repair in an epibenthic mollusc.
1375 Biology Letters 3, 314-317.
1376 Skovsted, C.B., Brock, G.A., Holmer, L.E., Topper, T.P. and Larsson, C.M. 2015b (in press).
1377 Revision of early Cambrian Tommotiid *Kulparina rostrata* from South Australia.
1378 Journal of Paleontology.
1379 Skovsted, C.B., Brock, G.A. and Paterson, J. 2006. Bivalved arthropods from the Lower
1380 Cambrian Mernmerna Formation, Arrowie Basin, South Australia and their
1381 implications for identification of Cambrian 'small shelly fossils'. Memoir of the
1382 Association of Australasian Palaeontologists 32, 7-41.
1383 Skovsted, C.B., Brock, G.A., Paterson, J.R., Holmer, L.E. and Budd, G.E. 2008. The
1384 scleritome of *Eccentrotheca* from the Lower Cambrian of South Australia:

1385 Lophophorate affinities and implications for tommotiid phylogeny. Geology 36, 171-
1386 174.
1387 Skovsted, C.B., Brock, G.A. and Topper, T.P. 2011a. Sclerite fusion in the problematic early
1388 Cambrian spine-like fossil *Stoibostrombus* form South Australia. Bulletin of
1389 Geosciences 86, 651-658.
1390 Skovsted, C.B., Brock, G.A. and Topper, T.P. 2012. First occurrence of a new *Ocruranus*-
1391 like helcionelloid mollusc from the Lower Cambrian of east Gondwana. Gondwana
1392 Research 22, 256-261.
1393 Skovsted, C.B., Brock, G.A., Topper, T.P., Paterson, J.R. and Holmer, L.E. 2011b.
1394 Scleritome construction, biofacies, biostratigraphy and systematics of the tommotiid
1395 *Eccentrotheca helenia* sp. nov. from the Early Cambrian of South Australia.
1396 Palaeontology 54, 253-286.
1397 Skovsted, C.B., Clausen, S., Álvaro, J.J., Ponlevé, D., 2014a. Tommotiids from the early
1398 Cambrian (Series 2, Stage 3) of Morocco and the evolution of the tannuolinid
1399 scleritome and setigerous shell structures in stem group brachiopods. Palaeontology
1400 57, 171-192.
1401 Skovsted, C.B., Holmer, L.E., 2003. The Early Cambrian (Botomian) stem group brachiopod
1402 *Mickwitzia* from Northeast Greenland. Acta Palaeontologica Polonica 48, 1-20.
1403 Skovsted, C.B., Holmer, L.E., Larsson, C.M., Högström, A.E.S., Brock, G.A., Topper, T.P.,
1404 Balthasar, U., Petterson-Stolk, S. and Paterson, J.R. 2009c. The scleritome of
1405 *Paterimitra*: An Early Cambrian stem group brachiopod from South Australia.
1406 Proceedings of the Royal Society B 276, 1651-1656.
1407 Skovsted, C.B., Pan, B., Topper, T.P., Betts, M.J., Li, G., Brock, G.A. 2016. The operculum
1408 and mode of life of the lower Cambrian hyolith *Cupitheca* from South Australia and
1409 North China. Palaeogeography, Palaeoclimatology, Palaeoecology 443, 123–130.

1410 Skovsted, C.B., Topper, T.P., Betts, M.J., Brock, G.A., 2014b. Associated conchs and
1411 opercula of *Triplicatella disdoma* (Hyolitha) from the early Cambrian of South
1412 Australia. Alcheringa 38, 148-153.
1413 Smith, D.G., Bailey, R.J., Burgess, P.M., Fraser, A.J. 2015. Strata and time: probing the gaps
1414 in our understanding. Geological Society, London, Special Publications 404, 1-10.
1415 Smith, A.G., Barry, T., Bown, P., Cope, J., Gale, A., Gibbard, P., Gregory, J., Hounslow, M.,
1416 Kemp, D., Knox, R. 2014. GSSPs, global stratigraphy and correlation. Geological
1417 Society, London, Special Publications 404, 37-67.
1418 Steiner, M., Li, G., Qian, Y. and Zhu, M. 2004. Lower Cambrian small shelly fossils of
1419 northern Sichuan and southern Shaanxi (China), and their biostratigraphic importance.
1420 Geobios 37, 259-275.
1421 Steiner, M., Li, G., Qian, Y., Zhu, M. and Erdtmann, B.-D. 2007. Neoproterozoic to Early
1422 Cambrian small shelly fossil assemblages and a revised biostratigraphic correlation of
1423 the Yangtze Platform (China). Palaeogeography, Palaeoclimatology, Palaeoecology
1424 254, 67-99.
1425 Swart, P.K. 2008. Global synchronous changes in the carbon isotopic composition of
1426 carbonate sediments unrelated to changes in the global carbon cycle. Proceedings of
1427 the National Academy of Sciences, *105*(37), 13741-13745.
1428 Swart, P.K. and Eberli, G. 2005. The nature of the $\delta^{13}C$ of periplatform sediments:
1429 implications for stratigraphy and the global carbon cycle. Sedimentary Geology 175,
1430 115-129.
1431 Tate, R., 1892. The Cambrian fossils of South Australia. Transactions of the Royal Society of
1432 South Australia 15, 183-189.

1433 Taylor, T.G., 1910. The Archaeocyathinae from the Cambrrian of South Australia with an
1434 accountr of the morphology and affinities of the whole class. Memoir of the Royal
1435 Society of South Australia 2, 55-186.
1436 Topper, T.P. 2006. Lower Cambrian Palaeontology, Biostratigraphy and Geology of the
1437 Donkey Bore Syncline, South Australia. Unpublished Honours thesis, Macquarie
1438 University.
1439 Topper, T.P., Brock, G.A., Skovsted, C.B., Paterson, J.R., 2009. Shelly fossils from the
1440 Lower Cambrian *Pararaia bunyerooensis* Zone, Flinders Ranges, South Australia.
1441 Memoir of the Association of Australasian Palaeontologists 37, 199-246.
1442 Topper, T.P., Brock, G.A., Skovsted, C.B. and Paterson, J.R. 2011a. *Microdictyon* plates
1443 from the lower Cambrian Ajax Limestone of South Australia: Implications for species
1444 taxonomy and diversity. Alcheringa 35, 427-443.
1445 Topper, T.P., Skovsted, C.B., Brock, G.A. and Paterson, J.R. 2011b. The oldest bivalved
1446 arthropods from the early Cambrian of East Gondwana: Systematics, biostratigraphy
1447 and biogeography. Gondwana Research 19, 310-326.
1448 Topper, T.P., Holmer, L.E., Skovsted, C.B., Brock, G.A., Balthasar, U., Larsson, C.M.,
1449 Petterson-Stolk, S. and Harper, D.A.T. 2013a. The oldest brachiopods from the lower
1450 Cambrian of South Australia. Acta Palaeontologica Polonica 58, 93-109.
1451 Topper, T.P., Skovsted, C.B., Harper, D.A.T. and Ahlberg, P. 2013b. A bradoriid and
1452 brachiopod dominated shelly fauna from the Furongian (Cambrian) ofVästergötland,
1453 Sweden. Journal of Paleontology, 87, 69-83.
1454 Topper, T.P., Skovsted, C.B., Brock, G.A. and Paterson, J.R. 2007. New Bradoriids from the
1455 lower Cambrian Mernmerna Formation, South Australia: Systematics, biostratigraphy
1456 and biogeography. Memoir of the Association of Australasian Palaeontologists 33,
1457 67-100.

1458 Torell, O.M., 1870. Petrifacta suecana Formationis Cambricae. Lunds Universitets Årsskrift
1459 6, 1-14.
1460 Ushatinskaya, G., 2012. The oldest Lingulids of the Siberian Platform: Microornamentation
1461 and shell structure. Paleontological Journal 46, 1298-1308.
1462 Vannier, J., Williams, M., Álvaro, J. J., Vizcaïno, D., Monceret, S., and Monceret, E. 2005.
1463 New Early Cambrian bivalved arthropods from southern France. Geological
1464 Magazine 142, 751-763.
1465 Varlamov, A.I., Rozanov, A.Y., Khomentovsky, V.V., Shabanov, Y.Y., Abaimova, G.P.,
1466 Demidenko, Y.E., Karlova, G.A., Korovnikov, I.V., Luchinina, V.A.,
1467 Malakhovskaya, Y.E., Parkhaev, P.Y., Pegel, T.V., Skorlotova, N.A., Sundukov,
1468 V.M., Sukhov, S.S., Fedorov, A.B., Kipriyanova, L.D., 2008. Excursions 2 and 3: The
1469 Southeast of the Siberian Platform (Southern Yakutia, Russia), In: Rozanov, A.Y.,
1470 A.I., V. (eds.), The Cambrian System of the Siberian Platform. XIII International
1471 Field Conference of the Cambrian Stage Subdivision Working Group, Moscow.
1472 Vostokova, V. A. 1962. Kembrijskie gastropody Sibiriskoj platformy i Tajmyra. Trudy
1473 Nauchno Issledovatel'skogo Instituta Geologii Arktiki 28, 51-74.
1474 Walcott, C. D. 1905. Cambrian faunas of China. Proceedings of the United States National
1475 Museum 29, 1–106.
1476 Walcott, C.D. 1912. Cambrian Brachiopoda. Monograph of the United States Geological
1477 Survey 51 (two volumes), 872 pp.
1478 Walcott, C.D. 1920. Middle Cambrian Spongiae. Smithsonian Miscellaneous Collections 67,
1479 261-364.
1480 Walter, M.R. 1967. Archaeocyatha and the biostratigraphy of the lower Cambrian Hawker
1481 Group, South Australia. Journal of the Geological Society of Australia 14, 139-152.

1482 Wells, A.T., Forman, D.J., Ranford, L.C. and Cook, P.J. 1970. Geology of the Amadeus
1483 Basin, central Australia. Bulletin - Australia, Bureau of Mineral Resources, Geology
1484 and Geophysics 100, 222.
1485 Wells, A.T., Ranford, L.C., Stewart, A.J., Cook, P.J. and Shaw, R.D. 1967. The geology of
1486 the northeastern part of the Amadeus Basin, Northern Territory. Bureau of Mineral
1487 Resources, Geology and Geophysics 113, 93.
1488 Williams, M., Siveter, D., 1998. British Cambrian and Tremadoc bradoriid and
1489 phosphatocopid arthropods. Monograph of the Palaeontographical Society 152, 49-49.
1490 Williams, M., Siveter, D.J., Popov, L.E., Vannier, J.M.C., 2007. Biogeography and affinities
1491 of the bradoriid arthropods: Cosmopolitan microbenthos of the Cambrian seas.
1492 Palaeogeography, Palaeoclimatology, Palaeoecology 248, 202-232.
1493 Woodward, H. 1884. Note on the Remains of Trilobites from South Australia. Geological
1494 Magazine 1, 342-344.
1495 Wrona, R. 2004. Cambrian microfossils from glacial erratics of King George Island,
1496 Antarctica. Acta Palaeontologica Polonica 49, 13-56.
1497 Yang, B., Steiner, M., Li, G. and Keupp, H. 2014. Terreneuvian small shelly faunas of East
1498 Yunnan (South China) and their biostratigraphic implications. Palaeogeography,
1499 Palaeoclimatology, Palaeoecology 398, 28-58.
1500 Young, G.C. and Laurie, J.R. 1996. An Australian Phanerozoic Timescale, Melbourne,
1501 Oxford University Press.
1502 Yuan, J., Zhu, X., Lin, J. and Zhu, M., 2011. Tentative correlation of Cambrian Series 2
1503 between South China and other continents. Bulletin of Geosciences 86, 397-404.
1504 Yue, Z. 1987. The discovery of *Tannuolina* and *Lapworthella* from Lower Cambrian in
1505 Meishucun (Yunnan) and Maidiping (Sichuan) sections. Professional Papers of

1506 Stratigraphy and Palaeontology, Chinese Academy of Geological Sciences 16,173-
1507 180 (in Chinese, with English abstract).
1508 Zang, W.-L., Jago, J.B., Alexander, E.M. and Paraschivoiu, E. 2004. A review of basin
1509 evolution, sequence analysis and petroleum potential of the frontier Arrowie Basin,
1510 South Australia. In, Boult, P. J., Johns, D.R., Lang, S.C. (eds.) Eastern Australian
1511 Basins Symposium II. Petroleum Exploration Society of Australia, Special
1512 Publication.
1513 Zang, W.-L., Moczydlowska, M. and Jago, J.B. 2007. Early Cambrian acritarch assemblage
1514 zones in South Australia and global correlation. Memoirs of the Association of
1515 Australasian Palaeontologists 33, 141-170.
1516 Zang, W.-L. 2002. Sequence analysis and petroleum potential in the Arrowie Basin, South
1517 Australia. Department of Primary Industries and Resources, South Australia, Report
1518 Book 24, 170.
1519 Zang, W.-L., Jago, J.B., Lin, T.-R. 2001. Early Cambrian acritarchs, trilobites and
1520 archaeocyathids from Yalkalpo 2, eastern Arrowie Basin, South Australia.
1521 Zhang, W.-T., 1974. A handbook of the stratigraphy and paleontology in Southwest China.
1522 Nanjing Institute of Geology and Palaeontology, Academica Sinica. Science Press,
1523 Beijing, pp. 107–111.
1524 Zhang, X.-G., 2007. Phosphatized Bradoriids (Arthropoda) from the Cambrian of China.
1525 Palaeontographica Abt. A, pp. 93-173.
1526 Zhou, B. and Xiao, L-G. 1984. Early Cambrian monoplacophorans and gastropods from
1527 Huainan and Huoqiu Counties (Anhui Provence). Professional Papers of Stratigraphy
1528 and Palaeontology 13, 125-140.

1529 Zhu, M., Babcock, L. and Peng, S.-C. 2006. Advances in Cambrian stratigraphy and
1530 paleontology: Integrating correlation techniques, paleobiology, taphonomy and
1531 paleoenvironmental reconstruction. Palaeoworld 15, 216-222.
1532 Zhuravlev, A.Y. and Gravestock, D.I. 1994. Archaeocyaths from Yorke Peninsula, South
1533 Australia and archaeocyathan Early Cambrian zonation. Alcheringa 18, 1-54.

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1535 Captions

1536 Fig. 1. Extent of Arrowie Basin, South Australia showing Cambrian outcrop and locations of
1537 measured sections.

1538 Fig. 2. AJX-M stratigraphic section through the Ajax Limestone in Mt. Scott, north-western
1539 Flinders Ranges. Ranges of key shelly fossil taxa through the *Micrina etheridgei* Zone and
1540 the *Dailyatia odyssei* Zone are shown. AJX-M has trilobite control; extent of the *Abadiella*
1541 *huoi* and *Pararaia tatei* Zones are shown. Abundance data is given in Appendix 1.

1542 Fig. 3. AJX-N stratigraphic section through the Ajax Limestone in Mt. Scott, north-western
1543 Flinders Ranges. Ranges of key shelly fossil taxa through the *Micrina etheridgei* Zone are
1544 shown. Abundance data is given in Appendix 2.

1545 Fig. 4. MORO stratigraphic section through the Parachilna Formation, Woodendinna
1546 Dolostone and Wilkawillina and Wirrapowie limestones in the Arrowie Syncline, northern
1547 Flinders Ranges. Ranges of key shelly fossil taxa through the *K. rostrata* Zone and the
1548 *Micrina etheridgei* Zone are shown. Abundance data is given in Appendix 3.

1549 Fig. 5. MOG stratigraphic section through the Wirrapowie and Wilkawillina limestones,
1550 Mernmerna Formation and Nepabunna Siltstone in the Arrowie Syncline, northern Flinders
1551 Ranges. Ranges of key shelly fossil taxa through the *Micrina etheridgei* Zone and the

1552 *Dailyatia odyssei* Zone are shown. Note the Flinders Unconformity is not developed in the
1553 Arrowie Syncline and the succession is largely continuous between the Wirrapowie
1554 Limestone and the Mernmerna Formation. Abundance data is given in Appendix 4.

1555 Fig. 6. WAR stratigraphic section through the Wirrapowie Limestone in the central Flinders
1556 Ranges. Ranges of key shelly fossil taxa through the *K. rostrata* Zone are shown. Abundance
1557 data is given in Appendix 5.

1558 Fig. 7. BALC stratigraphic section through the Parachilna Formation, Wilkawillina
1559 Limestone and the Billy Creek Formation in the Bunkers Range, central Flinders Ranges. The
1560 Flinders Unconformity represents erosion of the upper Winnitinny Creek Member and non-
1561 deposition of the entire Mernmerna Formation, hence the *D. odyssei* Zone is not present in
1562 the BALC section. Ranges of key shelly fossil taxa through the *K. rostrata* Zone and the
1563 *Micrina etheridgei* Zone. Abundance data is given in Appendix 6.

1564 Fig. 8. MMT stratigraphic section through the Wilkawillina Limestone and Mernmerna
1565 Formation in the Bunkers Range, central Flinders Ranges. The Flinders Unconformity (FU)
1566 occurs at horizon MMT/295.5 where the Third Plain Creek Member of the Mernmerna
1567 Formation (*P. bunyerooensis* trilobite zone) lies unconformably on the Winnitinny Creek
1568 Member of the Wilkawillina Limestone. Hence, the Six Mile Bore and Linns Springs
1569 members of the Mernmerna Formation are missing. The *D. odyssei* Zone is indicated by the
1570 occurrence of *Stoibostrombus crenulatus* but does not represent the true base of the zone due
1571 to the FU. Abundance data is given in Appendix 7.

1572 Fig. 9. WILK (Wilkawillina Limestone type section) stratigraphic section through the
1573 Woodendinna Dolostone, Wilkawillina Limestone and Mernmerna Formation in the Bunkers
1574 Graben, central Flinders Ranges. The Flinders Unconformity (FU) in the WILK section
1575 represents a time break between the Winnitinny Creek and Second Plain Creek members of

1576 the Wilkawillina Limestone. The true base of the *D. odyssei* Zone is difficult to ascertain due
1577 to the unknown time gap represented by the "reddened horizon". Additional sampling
1578 between the horizons immediately above and below the FU will clarify boundaries.
1579 Abundance data is given in Appendix 8.

1580 Fig. 10. 10MS-W stratigraphic section through the Parachilna Formation, Wilkawillina
1581 Limestone and the Mernmerna Formation in the south-eastern Bunkers Graben, central
1582 Flinders Ranges. Ranges of key shelly fossil taxa through the *K. rostrata* Zone and the
1583 *Micrina etheridgei* Zone are shown. Abundance data is given in Appendix 9.

1584 Fig. 11. CR1 stratigraphic section through the Wirrapowie Limestone in the Chase Range,
1585 southern Flinders Ranges. Ranges of key shelly fossil taxa through the *K. rostrata* Zone and
1586 the *M. etheridgei* Zone are shown. Abundance data is given in Appendix 10.

1587 Fig. 12. Correlation of all stratigraphic sections within the Arrowie Basin based on
1588 stratigraphic extent of the *K. rostrata* Zone, the *Micrina etheridgei* Zone and the *Dailyatia*
1589 *odyssei* Zone.

1590 Fig. 13. Shelly taxa typical of the *K. rostrata* Zone; *Askepasma saproconcha*, *Kulparina*
1591 *rostrata* and *Paterimitra pyramidalis*. A-G, *A. saproconcha* all from Wirrapowie Limestone.
1592 A, dorsal valve, CR1/108.0, SAM P53154. B, ventral valve, CR1/129.0, SAM P53155. C,
1593 ventral valve CR1/108.0, SAM P53156. D, dorsal valve CR1/114.0, SAM P53157. E, dorsal
1594 valve CR1/141.0, SAM P53158. F, ventral valve CR1/129.0, SAM P 53159. G, dorsal valve
1595 CR1/129.0, SAM P53160. H-N, Q, *K. rostrata* all from Hideaway Well Member (HWM) of
1596 the Wilkawillina Limestone. H, MMT/65.7, SAM P53161. I, MMT/76.6, SAM P53162. J,
1597 MMT/44.3, SAM P53163. K, MMT/71.9, SAM P53164. L, MMT/76.6, SAM P53165. M,
1598 MMT/76.6, SAM P53166. N, MMT/76.6, SAM P53167. Q, MMT/76.6, SAM P53170. O, P,
1599 R-V, *Paterimitra pyramidalis*. O and S, MMT/20.0, Wilkawillina Limestone (HWM), SAM

1600 P53168. P, MORO/933.2, Wirrapowie Limestone, SAM P53169. R, MORO/Spot Locality
1601 Aa (Betts et al., 2014), Wilkawillina Limestone (HWM), SAM P53171. T, MMT/126.5,
1602 Winnitinny Creek Member (WTCM) of the Wilkawillina Limestone, SAM P53172. U,
1603 MORO/881.6, Wilkawillina Limestone (WTCM), SAM P53173. V, MORO/730.0,
1604 Wilkawillina Limestone (HWM), SAM P53174.

1605 Fig. 14. *Dailyatia* species occurring in the *K. rostrata* Zone and the *M.etheridgei* Zone. A-G,
1606 *D. ajax*. A, A1 sclerite, MORO/1081.0, Wirrapowie Limestone, SAM P53175. B, B1 sclerite,
1607 MORO/881.6, SAM P53176. C, B2 sclerite, MORO/1081.0, Wirrapowie Limestone, SAM
1608 P53177. D, C1 sclerite, MOG/204.5, Wirrapowie Limestone, SAM P53178. E, reticulate
1609 microornament of *D. ajax*, MMT/237.5, Winnitinny Creek Member (WTCM) of the
1610 Wilkawillina Limestone, SAM P53179. F, B1 sclerite, MORO/1081, Wirrapowie Limestone,
1611 SAM P53180. G, C1 sclerite, MORO/589.0, Wilkawillina Limestone Hideaway Well
1612 Member (HWM), SAM P53181. H-K, *D. macroptera*. H, A1 sclerite, MORO/1081.0,
1613 Wirrapowie Limestone, SAM P53182. I, B sclerite, MORO/1043.0, Wirrapowie Limestone,
1614 SAM P53183. J, C1 sclerite, MORO/633.0, Wilkawillina Limestone (HWM), SAM P51384.
1615 K, C1 sclerite, MOG/201.0, Wirrapowie Limestone, SAM P53185. L-O, *D. helica*. L, A1
1616 sclerite, MORO/933.2, Wirrapowie Limestone, SAM P53186. M, B sclerite, MMT/237.5,
1617 Wilkawillina Limestone (WTCM), SAM P53187. N, C1 sclerite, MMT/195.5, Wilkawillina
1618 Limestone (WTCM), SAM P53188. O, C2a sclerite, MMT/243.1, Wilkawillina Limestone
1619 (WTCM), SAM P53189. P-S, *D. bacata*. P, A2 sclerite, MMT/109.0, Wilkawillina
1620 Limestone (WTCM), SAM P53190. Q, C2 sclerite, MMT/126.5, Wilkawillina Limestone
1621 (WTCM), SAM P53191. R, C1 sclerite, MMT/240.0, Wilkawillina Limestone (WTCM),
1622 SAM P53192. S, C1 sclerite, AJX-N/275.0, Ajax Limestone, SAM P53193.

1623 Fig. 15. *Eccentrotheca helenia* and *Micrina etheridgei* typical of the *M. etheridgei* Zone. A-I,
1624 *E. helenia*. A, MOG/210.0, Winnitinny Creek Member (WTCM) of the Wilkawillina

1625 Limestone, SAM P53194. B, D, MMT/237.5, Wilkawillina Limestone (WTCM), SAM
1626 P53195, SAM P53197. C, MORO/881.6, Wilkawillina Limestone (WTCM), SAM P53196.
1627 E, MMT/231.0, Wilkawillina Limestone (WTCM), SAM P53198. F-H, MOG/42.8,
1628 Wirrapowie Limestone, SAM P53199, SAM P53200, SAM P53201. I, MMT/237.5,
1629 Wilkawillina Limestone (WTCM), SAM P53202. J-P, *Micrina etheridgei*. J, sellate sclerite,
1630 MORO/Spot Locality F, Wirrapowie Limestone (Betts 2012), SAM P53203. K, sellate
1631 sclerite, MOG/170.0, Wirrapowie Limestone, SAM P53204. L, sellate sclerite, MOG/190.0,
1632 Wirrapowie Limestone, SAM P53205. M, N and P, mitral sclerites, MORO/Spot Locality F,
1633 SAM P53206, SAM P53207, SAM P53209. O, mitral sclerite, MMT/87.0, Wilkawillina
1634 Limestone (WTCM), SAM P53208.

1635 Fig. 16. *Askepasma toddense* and *Eoobolus* sp. from the *M. etheridgei* and *D.odyssei* Zones.
1636 A-H, *A. toddense*. A, exterior of dorsal valve, MMT/138.2, Winnitinny Creek Member
1637 (WTCM) of the Wilkawillina Limestone, SAM P53210. B(G) and C, exterior of dorsal valves
1638 showing four-lobed larval shell, MOG/912.0, Mernmerna Formation, SAM P53211, SAM
1639 P53212. D, interior of ventral valve, MOG/17.0, Wirrapowie Limestone, SAM P53213. E,
1640 interior of dorsal valve, MOG/10.5, Wirrapowie Limestone, SAM P53214. F, ventral valve,
1641 MORO/Spot Locality Aa (Betts et al., 2014), Hideaway Well Member of the Wilkawillina
1642 Limestone, SAM P53215. H, external reticulate microornament, MORO/1081.0, Wirrapowie
1643 Limestone, SAM P53216. I-U, *Eoobolus* sp. I (ventral valve) and N (dorsal valve)
1644 MOG/240.0, Winnitinny Creek Member (WTCM) of the Wilkawillina Limestone, SAM
1645 P53217, SAM P53222. J, MOG/223.0, Wilkawillina Limestone (WTCM), SAM P53218. K
1646 and O (ventral valves) MOG/404.0, Mernmerna Formation, SAM P53219, SAM P53223. L,
1647 dorsal valve, MOG/667.4, Mernmerna Formation, SAM P53220. M (dorsal valve) and P
1648 (ventral valve) MOG/382.2, Mernmerna Formation, SAM P53221, SAM P53224. Q, AJX-
1649 M/267.5, Ajax Limestone, SAM P53225. R and T, *Eoobolus* sp. dorsal valve with pustulose

1650 microornament AJX-M/274.0, Ajax Limestone, SAM P53226. S and U, *Eoobolus* sp. dorsal
1651 valve with pustulose microornament AJX-M/368.0, Ajax Limestone, SAM P53227.

1652 Fig. 17. *Karathele* (= *Schizopholis*) *yorkensis*, *Eodicellomus elkaniformiis*, *Minlatonia tuckeri*
1653 and *Kyrshabactella davidii* from the *M. etheridgei* Zone and the *D. odyssei* Zone. A-H, *K.*
1654 *yorkensis* all except B from the Ajax Limestone. A, C-E from AJX-M/387.0. A, ventral
1655 valve, SAM P53228. C, dorsal valve SAM P53230. D, ventral valve SAM P53231. E, ventral
1656 valve SAM P53232. B, dorsal valve from MOG/551.5, Mernmerna Formation, SAM P53229.
1657 F, ventral valve, AJX-M/368.0, SAM P53233. G, dorsal valve, AJX-M/388.0, SAM P53234.
1658 H, external microornament, AJX-M/267.5, SAM P53235. I-P, *Eodicellomus elkaniformiis*,
1659 and *Minlatonia tuckeri* all from the Ajax Limestone. I (ventral valve) and J (articulated), *E.*
1660 *elkaniformiis*, AJX-M/387.0, SAM P53236, SAM P53237. K, *E. elkaniformiis* dorsal valve,
1661 AJX-M/266.0, SAM P53238. L, *E. elkaniformiis* dorsal valve, AJX-M/357.5, SAM P53239.
1662 M, *E. elkaniformiis* ventral valve, AJX-M/305.0, SAM P53240. N, *M. tuckeri* ventral valve
1663 interior, AJX-M/217.5, SAM P53241. O, *M. tuckeri* dorsal valve exterior, AJX-M/256.0,
1664 SAM P53242. P, *M. tuckeri* dorsal valve larval shell, AJX-M/263.0, SAM P53243. Q-T, *K.*
1665 *davidii* all ventral valves. Q and T, MMT/240.0, Winnitinny Creek Member (WTCM) of the
1666 Wilkawillina Limestone, SAM P53224, SAM P53247. R, MMT/225.8, Wilkawillina
1667 Limestone (WTCM), SAM P53245. S, BALC/540.0, Wilkawillina Limestone (WTCM),
1668 SAM P53246.

1669 Fig. 18. Molluscan fauna from the *M. etheridgei* Zone and the *D. odyssei* Zone. *Pelagiella*
1670 steinkerns (A-D, G) and phosphatised coatings (E, F, H). A, MOG/42.8, Wirrapowie
1671 Limestone, SAM P53248. B, MOG/15.0, Wirrapowie Limestone, SAM P53249. C,
1672 MOG/264.7, Winnitinny Creek Member (WTCM) of the Wilkawillina Limestone SAM
1673 P53250. D, MORO/829.7, Wilkawillina Limestone (WTCM), SAM P53251. E, silicified
1674 shell, MMT/265.1, Wilkawillina Limestone (WTCM), SAM P53252. F and H, phosphatised

shells, MOG/0.0, Wirrapowie Limestone, SAM P53253, SAM P53255. G, BALC/580.0, Wilkawillina Limestone (WTCM), SAM P53254. I-M, *Anabarella* steinkerns (L and M with phosphatised coating). I and J, MORO/Spot Locality C (Betts *et al*., 2014), Wilkawillina Limestone (WTCM), SAM P53256, SAM P53257. K, MOG/42.8, Wirrapowie Limestone, SAM P53258. L and M steinkerns with shell, MOG/264.7, MOG/210.0, Wilkawillina Limestone (WTCM), SAM P53259, SAM P53260. N-U, *Mackinnonia* steinkerns (O with silicified shell material). N, R and T, MOG/264.7, Wilkawillina Limestone (WTCM), SAM P53261, SAM P53264, SAM P53266. O, steinkern with silicified shell, AJX-M/266.0, Ajax Limestone, SAM P50906. P, MOG/210.0, Wilkawillina Limestone (WTCM), SAM P53262. Q, close up of ornament on steinkern, AJX-M/271.3, Ajax Limestone, SAM P53263. S, MOG/247.0, Wilkawillina Limestone (WTCM), SAM P53265. U, MMT/138.2, Wilkawillina Limestone (WTCM), SAM P53267.

Fig. 19. Bradoriid fauna from the *M. etheridgei* Zone. A-D, *Jiucunella phaseloa*, all from Wirrapowie Limestone. A, left shield, MOG/0.0, SAM P53268. B, shields split along dorsal fold, MOG/33.3, SAM P51221. C, conjoined specimen with wide ventral gape, MOG/0.0, SAM P51222. D, right shield, MOG/31.2, SAM P53269. E-H, *Sinskolutella cuspidata*, all from MORO/933.2, Wirrapowie Limestone. E and F, left shield with well-preserved external microornament, SAM P48677. G, left shield, SAM P48671. H, left shield, SAM P48672. I-L, *Neokunmingella moroensis*, all from the Wirrapowie Limestone. I, left shield, MOG/10.0, SAM P51225. J, internal view of right shield, MOG/10.0, SAM P51226. K, conjoined specimen, MOG/10.0, SAM P51227. L, close up of external microornament, MOG/0.0, SAM P53270. M-R, *Mongolitubulus anthelios* shields, and spines.M, *M. anthelios* shield with central spine from MORO/881.6, from the Winnitinny Creek Member (WTCM) of the Wilkawillina Limestone, SAM P48700. N, *M. anthelios* shield with central spine missing from MOG/10.5, Wirrapowie Limestone, SAM P53275. O, R, *M. anthelios* spine showing

1700 rhomboid scales, MOG/114.1, Wirrapowie Limestone, SAM P53276. P, *M. anthelios* spine,
1701 MORO/889.0, Wilkawillina Limestone (WTCM), SAM P48697. Q, *M. anthelios* spine,
1702 MOG/15.0, Wirrapowie Limestone, SAM P53277. S, T, *Jixinlingella daimonikoa*, conjoined
1703 shields (holotype) MORO/1043.0, Wirrapowie Limestone, SAM P48683. U, *J. daimonikoa*
1704 left shield, MORO/1043.0, Wirrapowie Limestone, SAM P48684.

1705 Fig. 20. Bradoriid fauna from the *M. etheridgei* Zone and the *D. odyssei* Zone. A-D,
1706 *Parahoulongdonella bashanensis*. A-B, left shield, CR1/500.0, Wirrapowie Limestone SAM
1707 P53278. C- D, left shield, RC/102.0, Wirrapowie Limestone, SAM P53282. E-F, *Quadricona*
1708 *madonnae*, both from the Wirrapowie Limestone. E, conjoined specimen, RC/252.9, SAM
1709 P53283. F, right shield, RC/252.9, SAM P53285. G-H, *Albrunnicola bengtsoni*,
1710 BALC/580.0, Winnitinny Creek Member (WTCM) of the Wilkawillina Limestone, SAM
1711 P53280. I, *Euzepaera* sp. A., ER9/53.5, Wirrapowie Limestone. J-K, *Mongolitubulus* sp.,
1712 CR1/589.7, Wirrapowie Limestone, SAM P53281. L(O) and P, *Spinospitella coronata* all
1713 from BALC/580.0, Wilkawillina Limestone (WTCM). L, close up of spine tip from (O). O,
1714 broken spine, SAM P53284. P, broken spine with abraded ornament, SAM P53287. M-N, *S.*
1715 *coronata* shield fragment from ER9/0.0, Wirrapowie Limestone, SAM P44806.

1716 Fig. 21. Typical shelly fauna associated with the *Dailyatia odyssei* Zone. A-G and K,
1717 *Lapworthella fasciculata*. A, MOG/264.7, Winnitinny Creek Member (WTCM) of the
1718 Wilkawillina Limestone, SAM P53292. B and K, MOG/912.0, Mernmerna Formation, SAM
1719 P53293. C, AJX-N/382.4, Ajax Limestone, SAM P53294. D, MMT/268.0, Wilkawillina
1720 Limestone (WTCM), SAM P53295. E, MOG/905.4, Mernmerna Formation, SAM P53296. F,
1721 MMT/268.0, Wilkawillina Limestone (WTCM), SAM P53297. G, MMT/265.1, Wilkawillina
1722 Limestone (WTCM), SAM P53298. H-J and L, *Stoibostrombus crenulatus*. H and L,
1723 MOG/912.0, Mernmerna Formation, SAM P53299. I and J, MOG/905.4, Mernmerna
1724 Formation, SAM P53300, SAM P53301. M-O, *Dailyatia odyssei*, all C1 sclerites from the

Second Plain Creek Member of the Wilkawillina Limestone (WILK Type Section). M, WILK/S, SAM P53302. N and O, WILK/Q, SAM P53303, SAM P53304. P- S, Obolidae gen. et. sp. indet. all from AJX-M/357.0 in the Ajax Limestone. P, ventral valve, SAM P53305. Q, ventral valve, SAM P53306. R and S, dorsal valve, SAM P53307. T-V, sclerites from *Microdictyon* sp., all from the Winnitinny Creek Member of the Wilkawillina Limestone. T and U, MOG/215.0, SAM P53308. V, MOG/231.2, SAM P53309. W, *Mongolodus* sp. from COOP/RS377 in the Second Plain Creek Member of the Wilkawillina Limestone, SAM P53310. X, *Protohertzina* sp., from MOG/551.5 in the Mernmerna Formation, SAM P53311.

Fig. 22. Regional correlation of the *K. rostrata*, *M. etheridgei* and the *Dailyatia odyssei* zones. The assemblages can be confidently correlated between the Arrowie Basin and the western Stansbury Basin (Yorke Peninsula), eastern Stansbury Basin (Fleurieu Peninsula) based on co-occurrence of key fauna. Position of previous schemes utilising shelly fossils (Daily 1956) and archaeocyaths (Gravestock 1984) are also included. Note uncertainty of shelly fossil zonation in the Heatherdale Shale is due to lack of fauna. Dashed lines indicate boundaries are uncertain. Undulating lines indicate unconformities.

Fig. 23. Correlation of the *K. rostrata* and *M. etheridgei* zones with South China utilising key cosmopolitan genera. Figure adapted from Steiner et al (2007, figs 11 and 12); Yuan et al (2011, table 2); Peng et al. (2012, fig. 19.11); Yang et al (2013, fig. 5). Further global correlation is hindered by lack of cosmopolitan species in the *K. rostrata* and *M. etheridgei* zones. Dashed lines indicate boundaries are uncertain. Undulating lines indicate unconformities.

Author biographies

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John R. Paterson is a Professor of Earth Sciences and currently an Australian Research Council Future Fellow at the University of New England (UNE) in Armidale, New South Wales, Australia. He graduated with a BSc (Hons) (2001) and PhD (2005) from Macquarie University in Sydney. He completed postdoctoral studies at the South Australian Museum, Adelaide (2005) and Macquarie University (2006) before his appointment as a Lecturer at UNE in 2007. His main research interests include Cambrian faunas from East Gondwana, especially the Emu Bay Shale Konservat-Lagerstätte of South Australia. He has served as Secretary of the Association of Australasian Palaeontologists (AAP; 2006-2010), is currently a corresponding member of the International Subcommission on Cambrian Stratigraphy, and serves on the editorial boards of the peer-reviewed journals *Alcheringa*, *AAP Memoirs* and *Zootaxa*. He was recently awarded the 2016 Anton Hales Medal by the Australian Academy of Science.

Jim Jago is currently Adjunct Professor within the School of Natural and Built Environments, Mawson Lakes Campus, University of South Australia. Jim joined the South Australian Institute of Technology in 1971 and has continued at SAIT/University of South Australia. He is an Honorary Research Associate with the South Australian Museum. His main research interests are in Cambrian biostratigraphy, particularly of Tasmania, South Australia and Antarctica, and in the stratigraphy and sedimentology of the Cambrian of South Australia. He is a voting member of the Cambrian Subcommission.

Sarah M. Jacquet is a PhD student in the Department of Biological Sciences, Macquarie University in Sydney, Australia. She graduated with a BSc. (majoring in Palaeobiology) with Honours (2012) from Macquarie University. Her honours project focused on shelly fossil assemblages, palaeoenvironements and faunal dynamics of lower Cambrian carbonates from the north-east Flinders Ranges, South Australia. Her doctorate research now aims to better understand the early evolution and radiation of the Mollusca from the lower Cambrian of East Gondwana. This broad focus is channelled into various fields of interest including taxonomy, biostratigraphy, taphonomy and early ontogeny of ancestral macro- and micromolluscs.

Christian B. Skovsted is Senior Curator of invertebrate palaeontology at the Swedish Museum of Natural History, Stockholm, Sweden. From 2014 he also serves as Editor of *GFF*, the scientific journal of the Geological Society of Sweden. He received his PhD from Uppsala University in 2004 with a thesis concerning the Early Cambrian fauna of Small Shelly Fossils (SSF) from North East Greenland. Since then he has expanded his work to include Cambrian SSF faunas from all parts of the globe. In recent years he has mainly concentrated on the scleritome structure and taxonomy of the problematic *tommotiids*, a group of multi-plated fossils which have turned out to be closely related to brachiopods.

Timothy P. Topper is a postdoctoral researcher at the Swedish Museum of Natural History, Stockholm, Sweden. His interests are devoted to unravelling the events surrounding one of the most profound phases of evolutionary change in the history of life on Earth, the Cambrian Explosion. He studied Geology and Palaeontology at Macquarie University and obtained his PhD in 2010 at Macquarie University; a thesis focused on Cambrian shelly faunas of South Australia. Since then his research has expanded to include fossil assemblages from Sweden, Denmark, Greenland and North America. Recently his focus is directed towards understanding the palaeoecology of the brachiopods in the Burgess Shale Lagerstätte. Soon he will relocate to Durham University where his work will lead him to the Cambrian deposits of North Greenland.

Glenn A. Brock is an Associate Professor of Palaeobiology in the Department of Biological Sciences, Macquarie University, New South Wales, Australia. His interdisciplinary research program focuses on detailed exploration of the Cambrian Radiation of animal life which heralds the emergence and rapid diversification of the major animal body plans and the birth of animal-based ecosystems. He has served as Honorary Editor (1996-2000) of *Alcheringa*, the Australasian journal of Palaeontology and President (2007-2010) of the Australasian Association of Palaeontologists (AAP). Internationally, he has been a visiting Scholar/Professor at the Institute of Advanced Studies, Durham University, UK and the Department of Earth Sciences, Uppsala University Sweden. He is a corresponding member of the International Subcommission on Cambrian Stratigraphy, and has been part of the organising committee of major palaeobiological congresses – including co-chairing the 1st International Palaeontological Congress in Sydney (2002).